Landscape & Strings in vacqua

Olga Mena
Universita di Roma
“La Sapienza”

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Antarctica & Strings in vacqua!

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The Ultra High Energy Neutrino MENU:

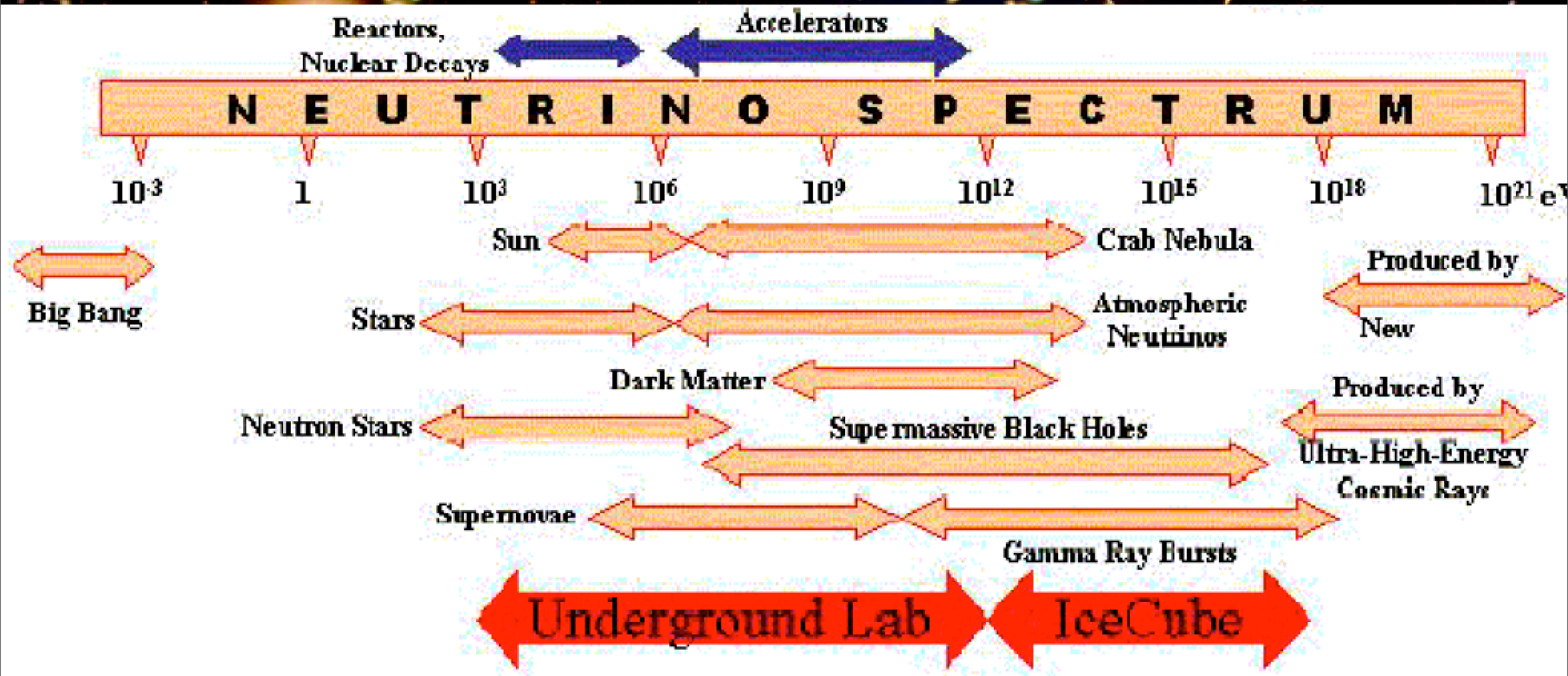
Antipasto: Multi-messenger neutrino astronomy
Detection techniques and current limits

Primo piatto: Matter effects in astrophysical sources

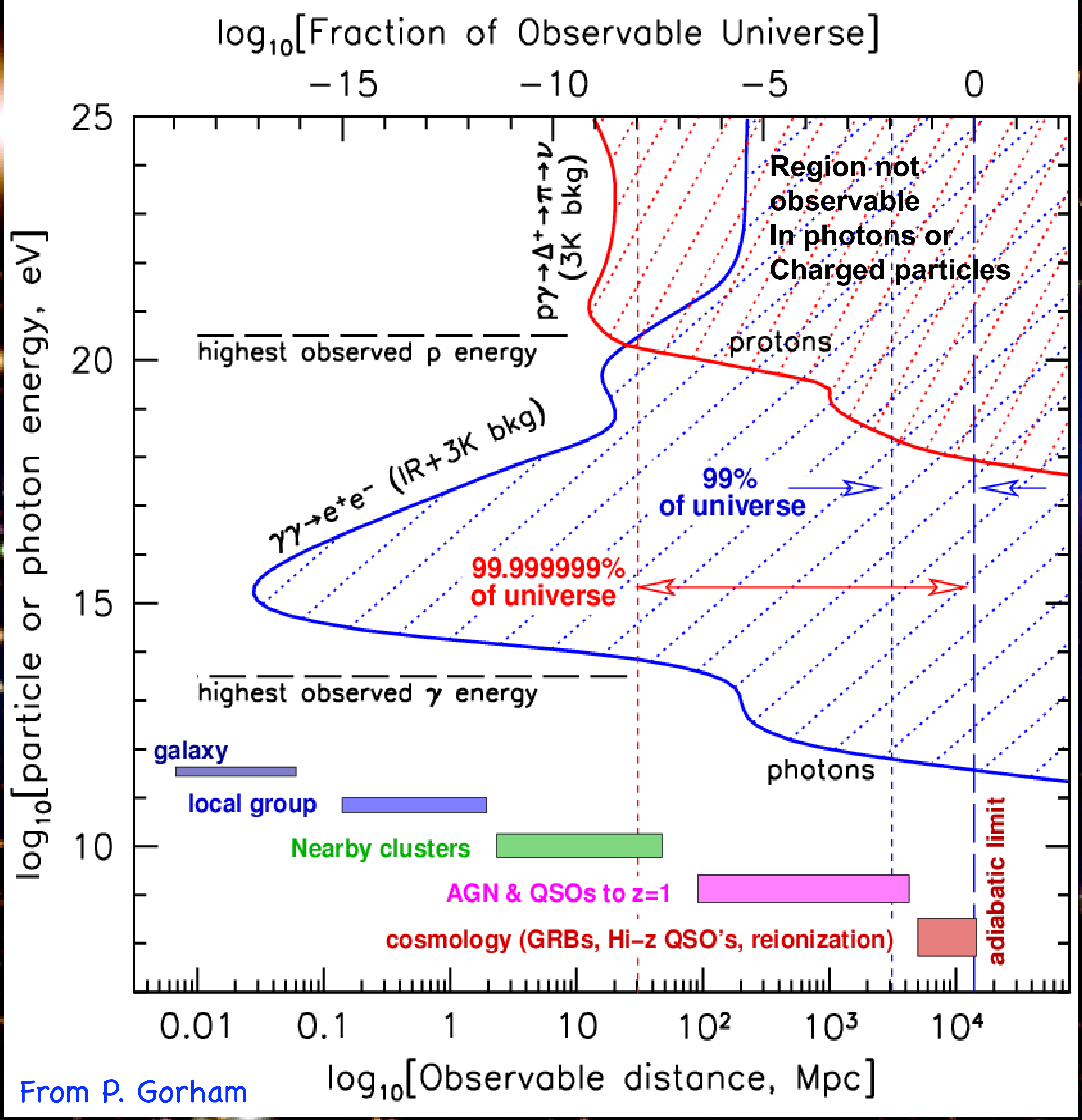
Secondo piatto: GZK neutrinos as a probe of large extradimensions

Caffe & Dolci (outside)!

Multi-messenger neutrino astronomy

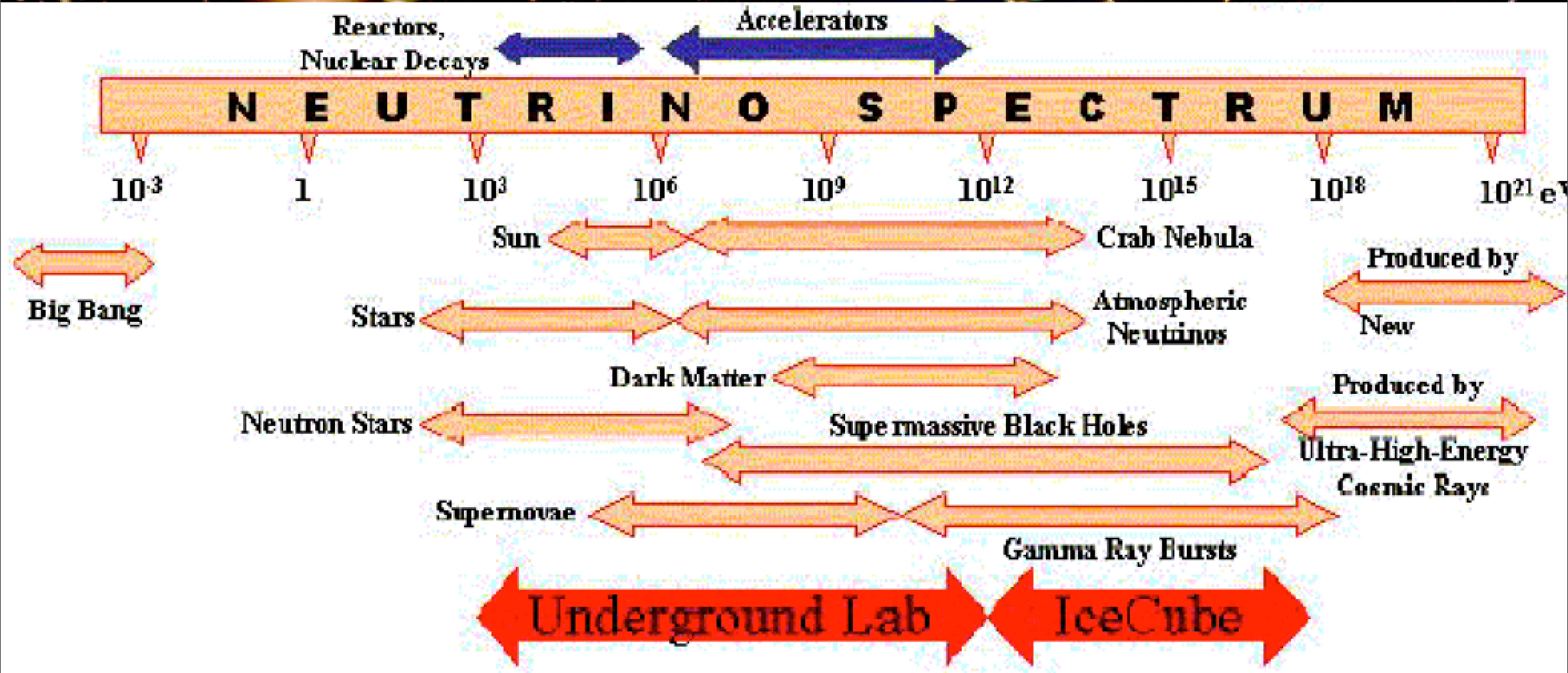


Multi-messenger neutrino astronomy



From P. Gorham

Multi-messenger neutrino astronomy.



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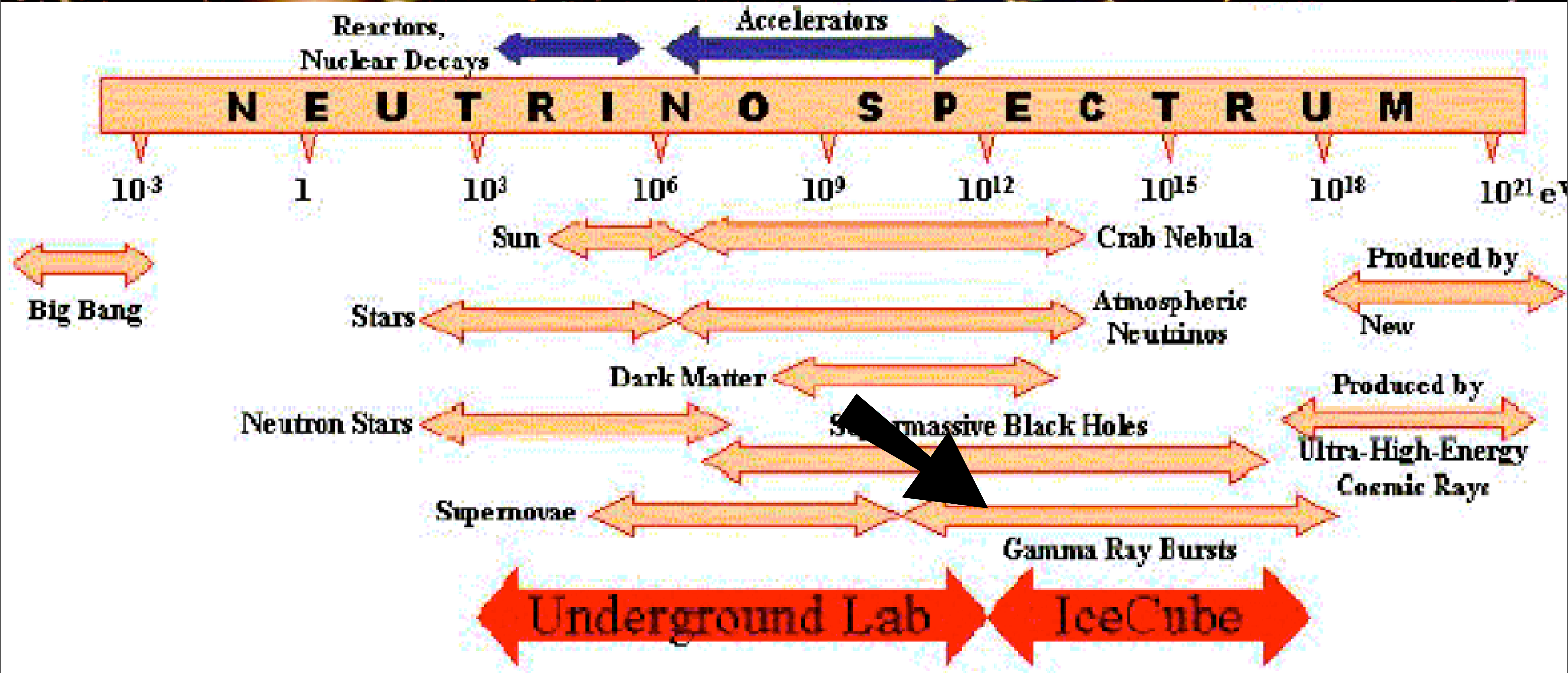

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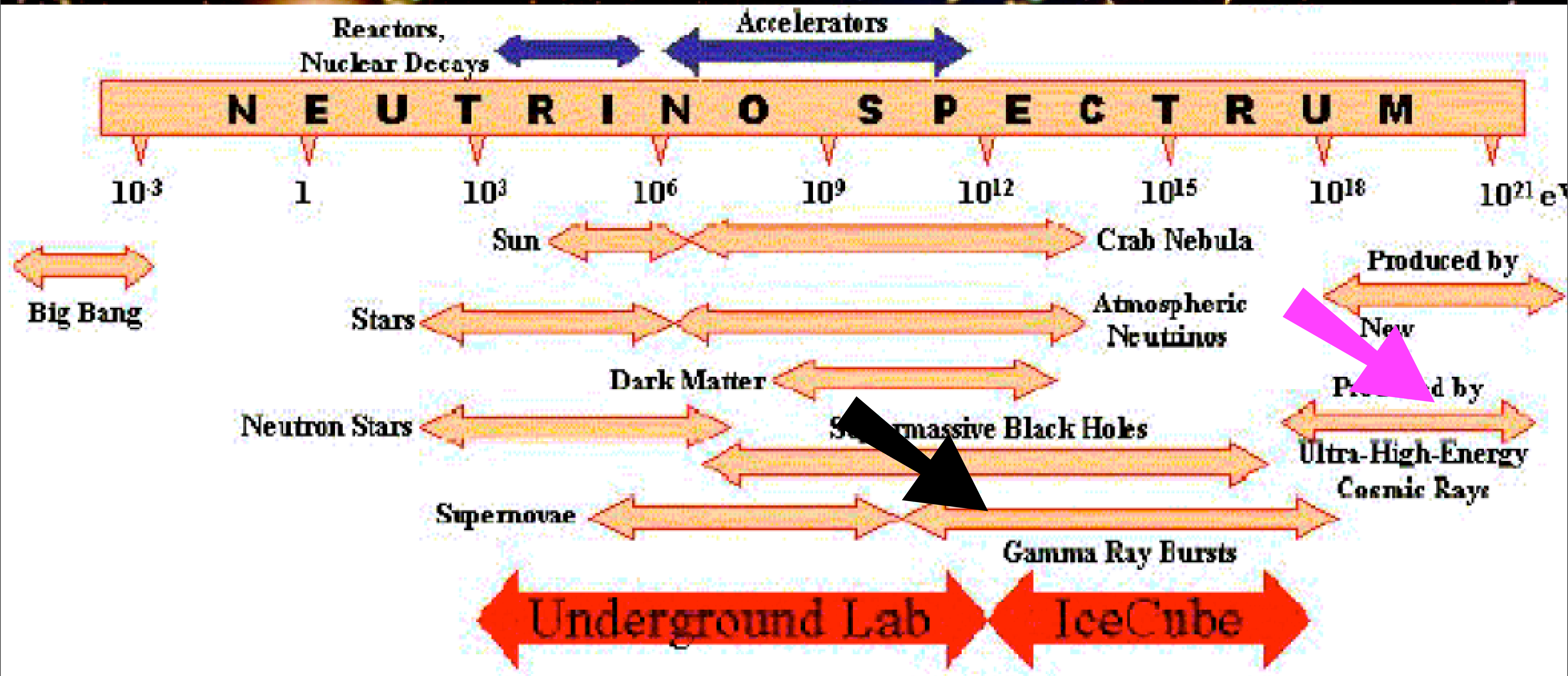

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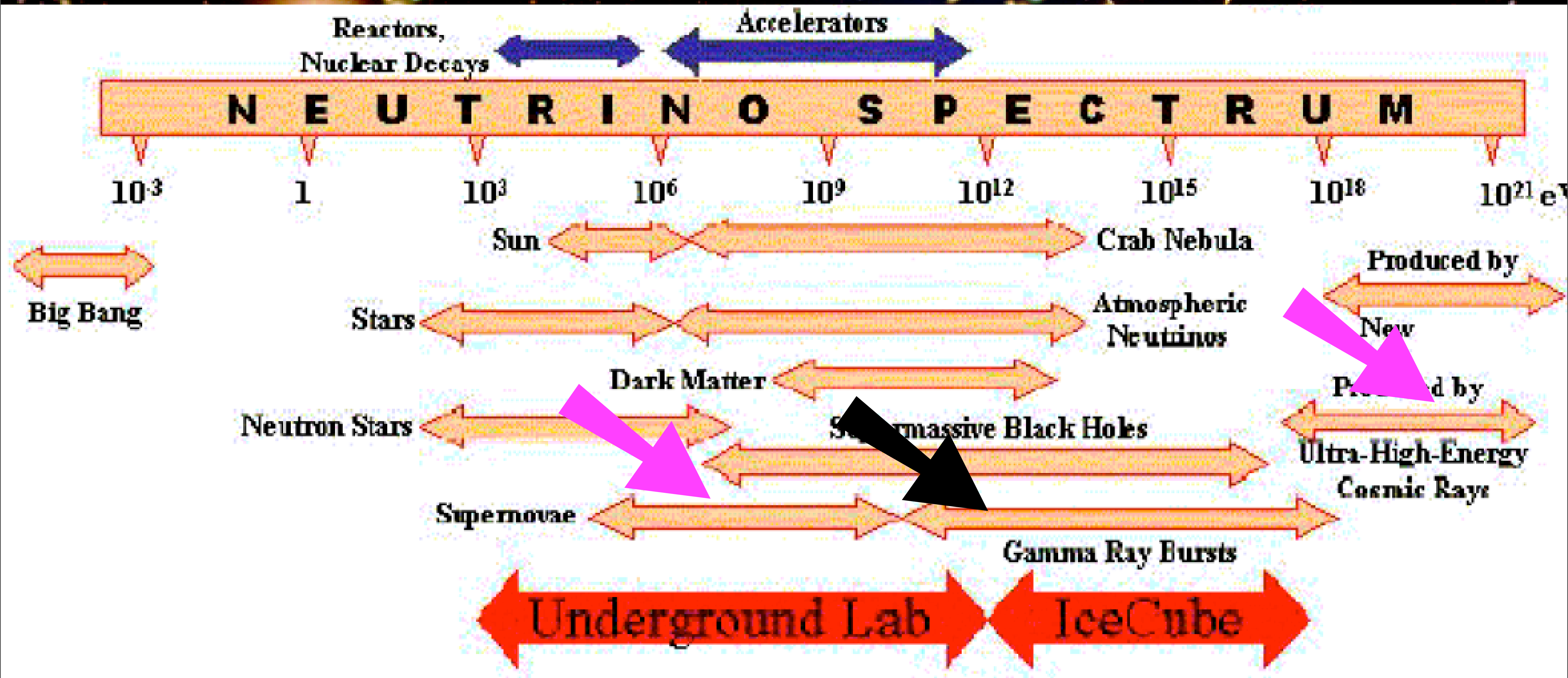
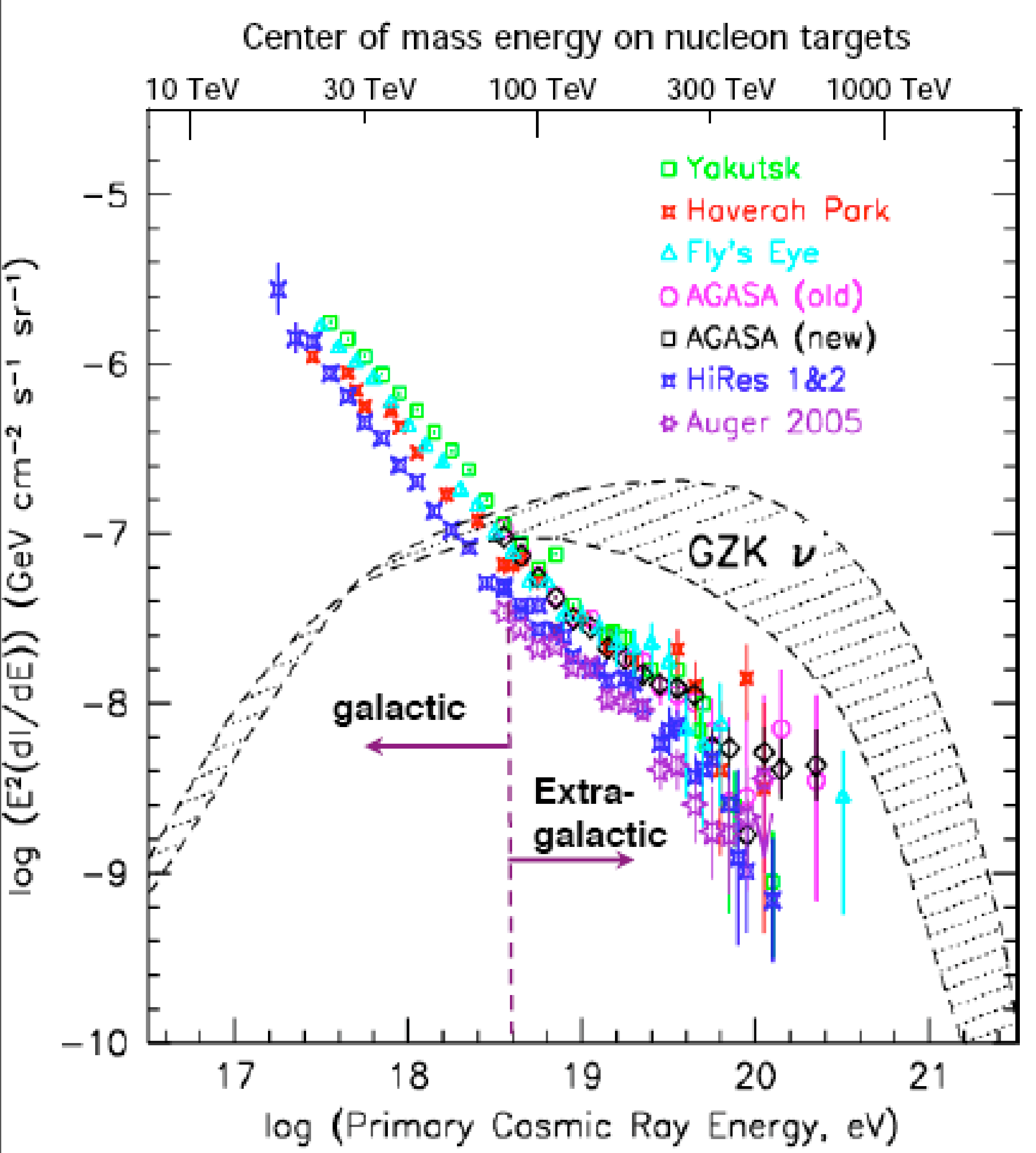


Super powerful cosmic accelerator engines



P. Gorham

Because their connection with UHE cosmic rays, which have been observed! However, the mystery has not been solved... what is their origin?

Sources

Guaranteed

- "GZK" neutrinos:

$$p + \gamma \to ... \to \pi^+ \to \mu^+ + \nu_\mu$$
$$\downarrow$$
$$e^+ + \bar{\nu}_\mu + \nu_e$$

- Gamma Ray Bursts

- Active Galactic Nuclei

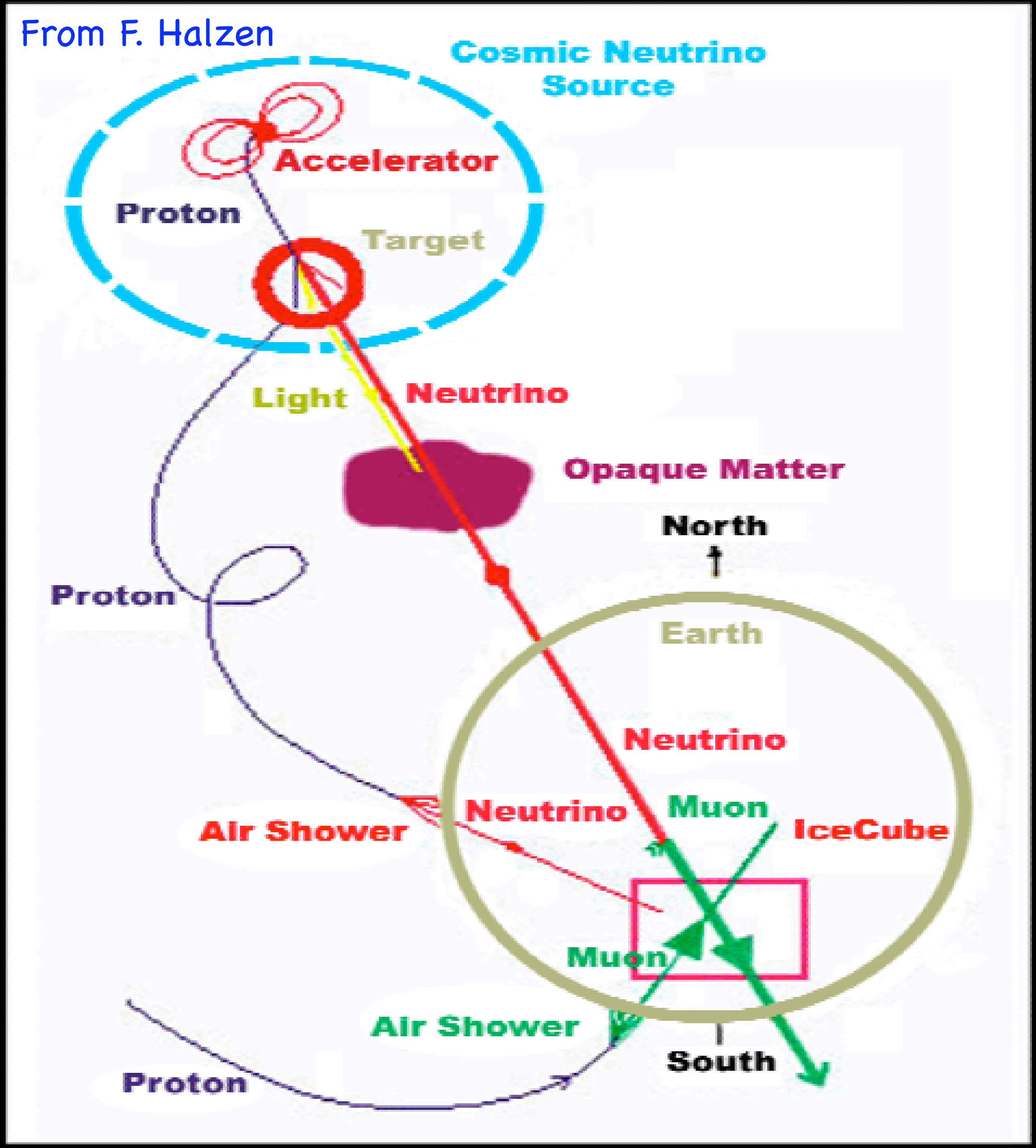
- Topological Defects

- Decay of Super-Massive Particles

...

Highly speculative

Energies higher than colliders!



UHE neutrinos as Cosmic messengers:

Unlike photons, neutrinos interact weakly, so they are not attenuated.

Unlike protons, neutrinos are NOT deflected by magnetic fields: their arrival direction points back to the source: NEUTRINO ASTRONOMY

Conditions at the astrophysical source perhaps inaccessible with photons, probe cross sections at extreme energies, where new physics may show up (Extra dimensional interactions), exotic neutrino properties (neutrino decay)

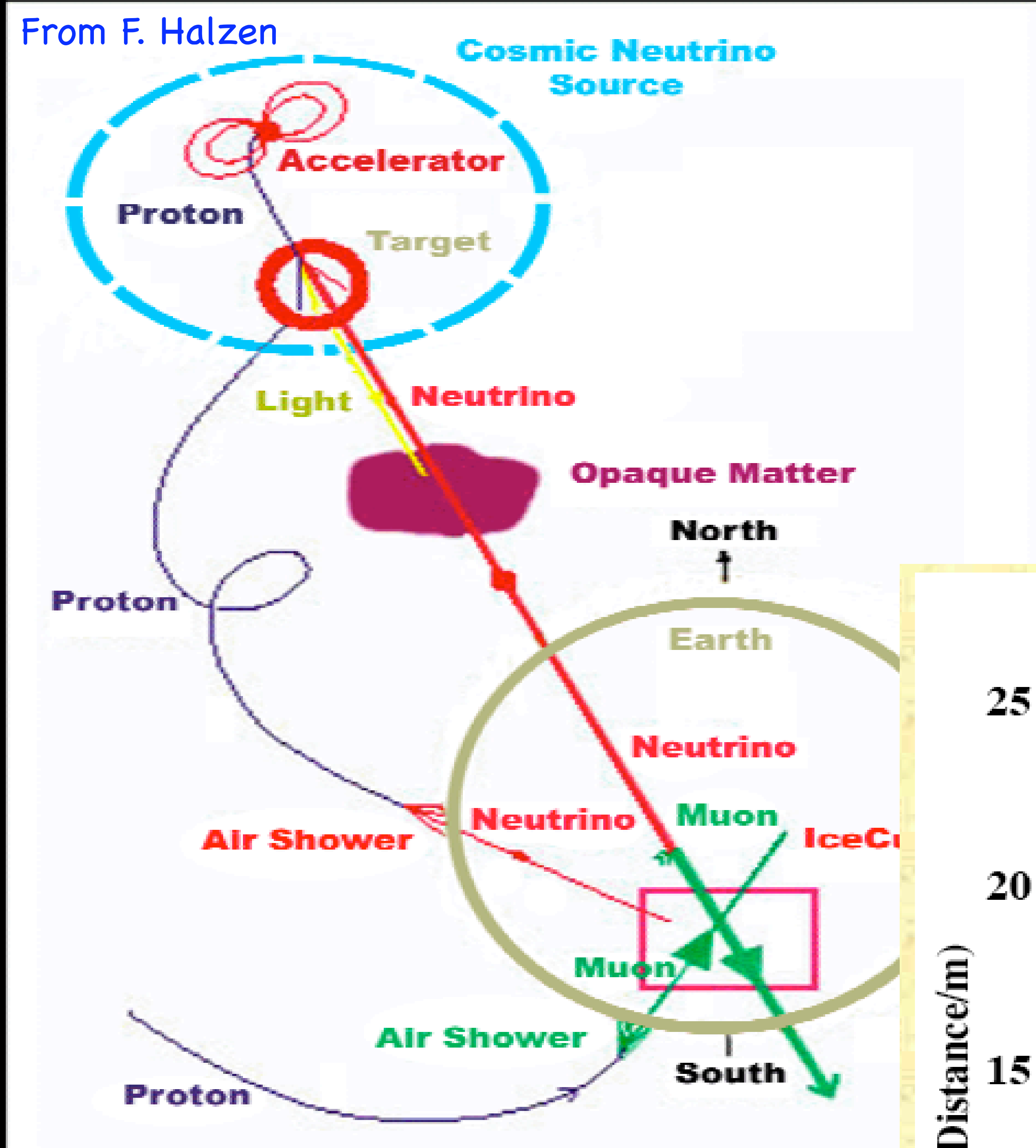
Astrophysical sources provide baselines almost as big as the visible universe, very high neutrino energies not accessible at man-made neutrino beams.

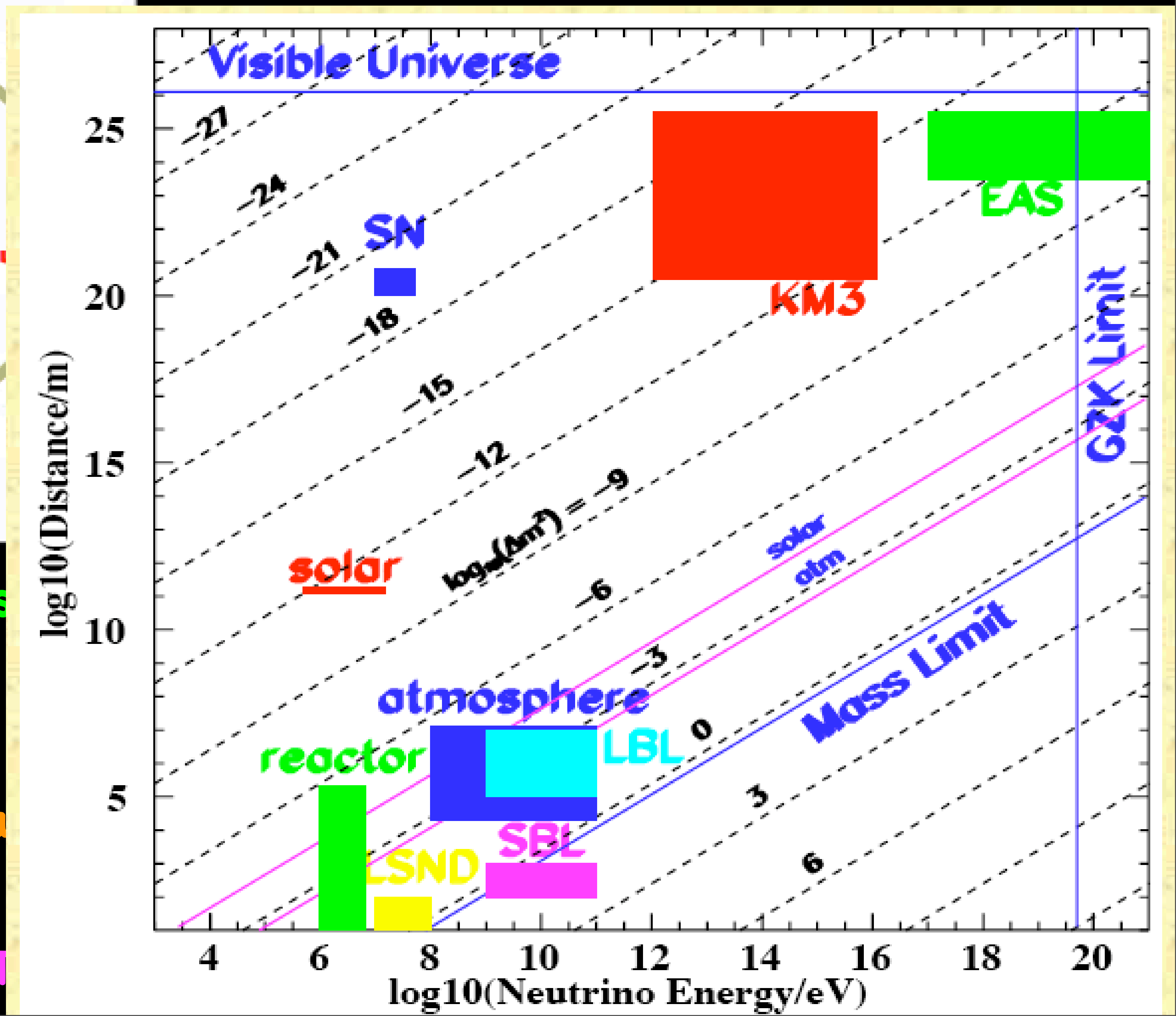
Astrophysical/Cosmological and Terrestrial neutrino experiments help each other.

UHE neutrinos as Cosmic messengers:

Unlike photons, neutrinos interact weakly, so they are not attenuated.

From F. Halzen





Conditions at the astrophysical s
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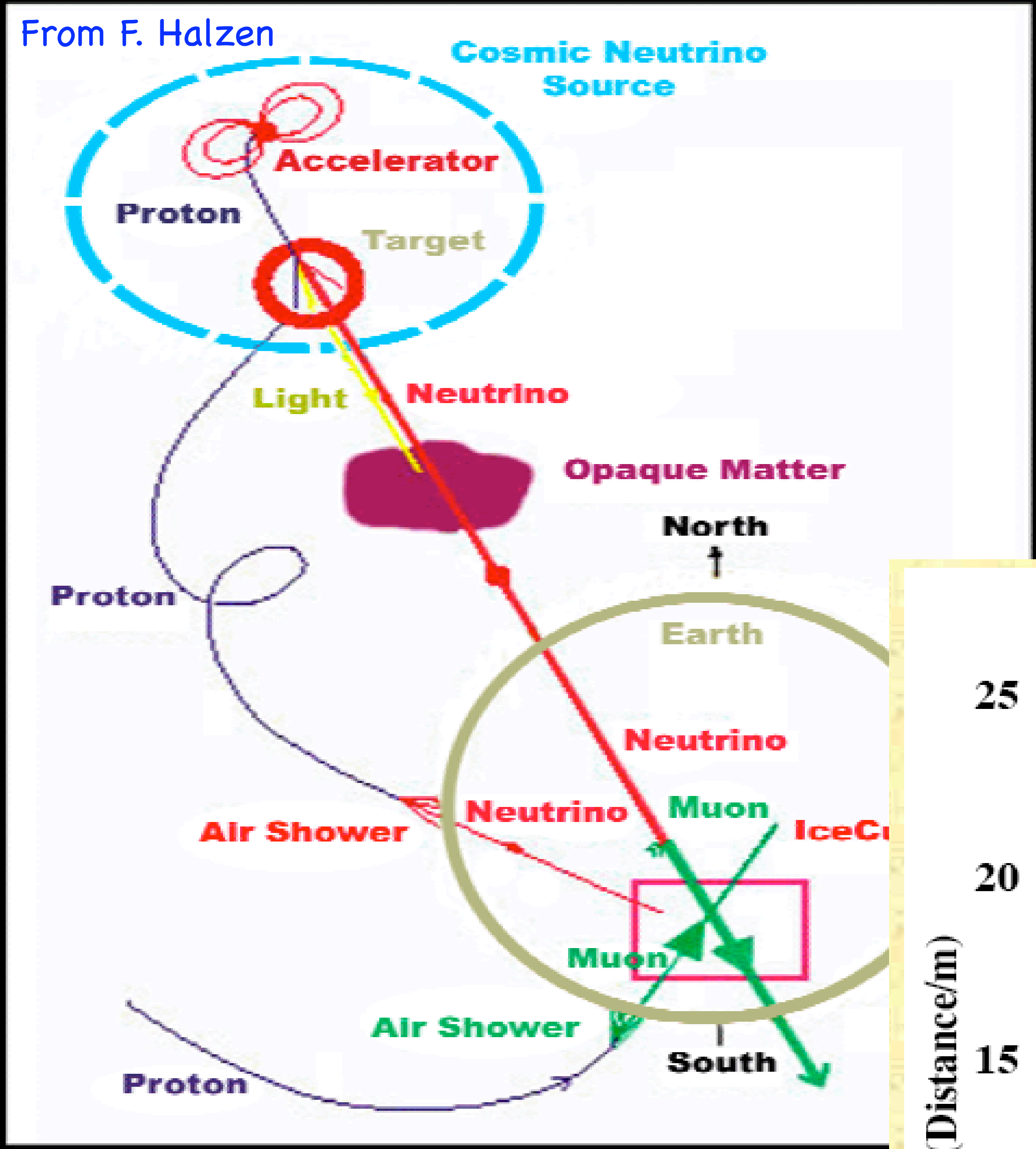

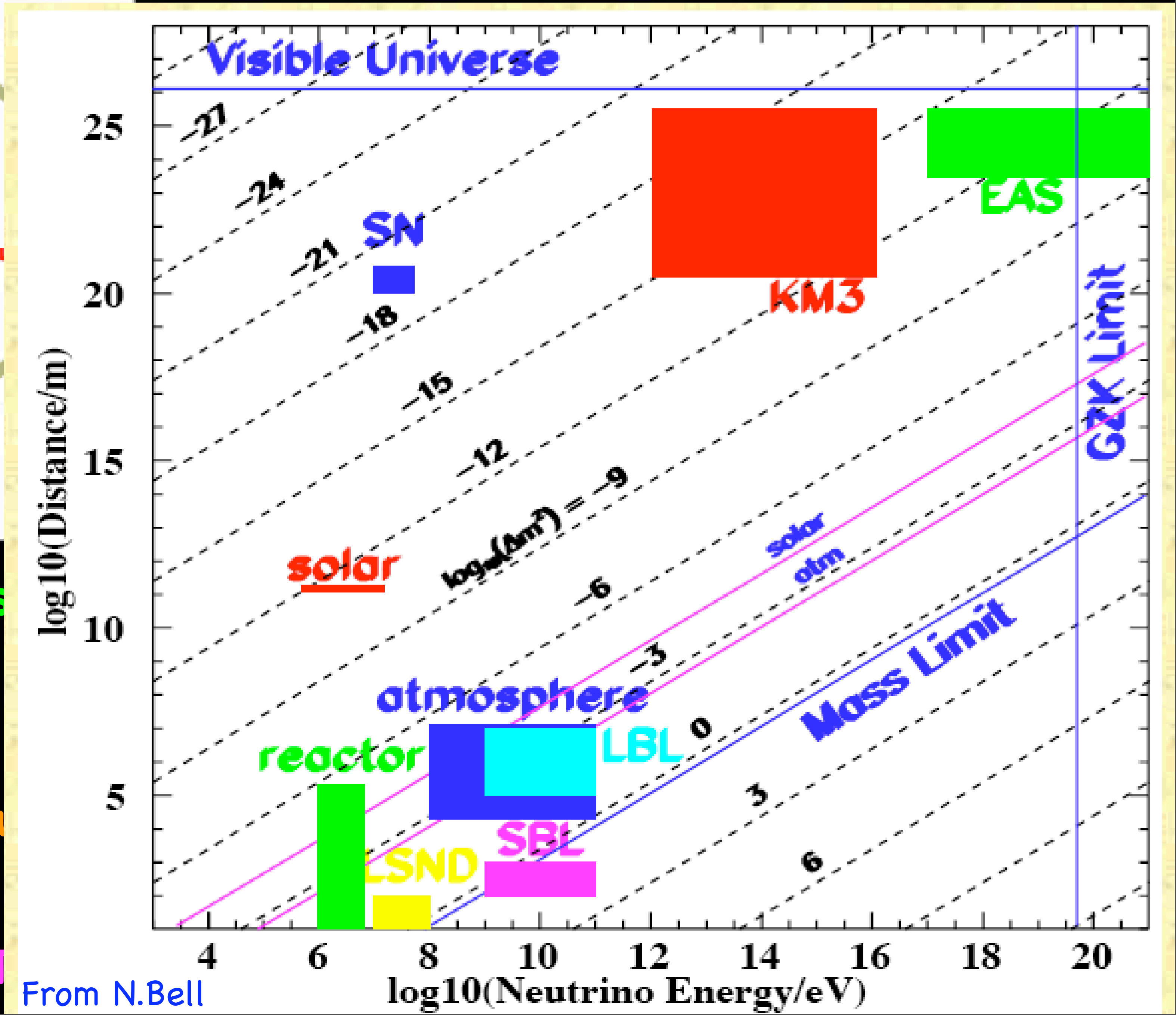

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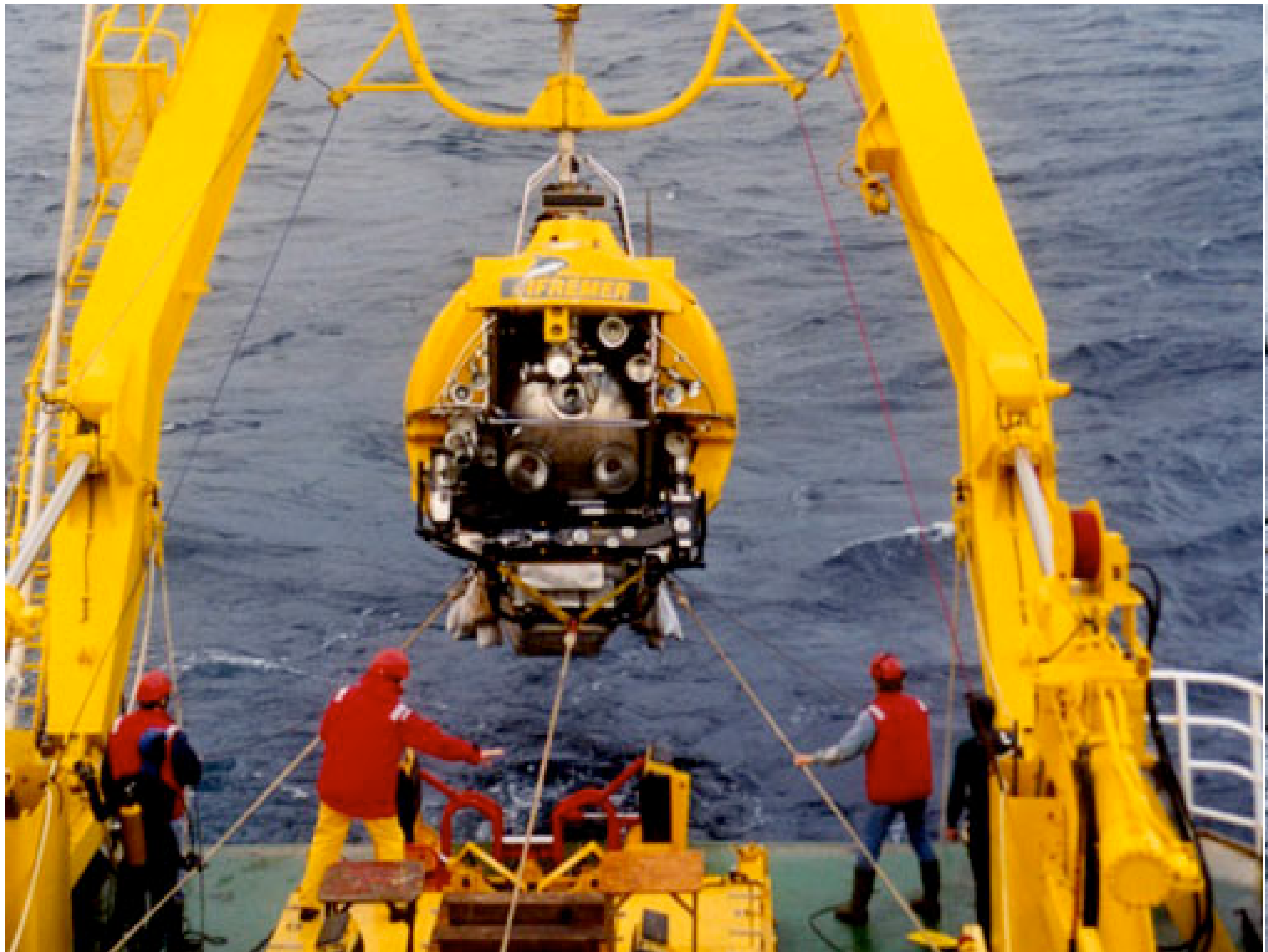
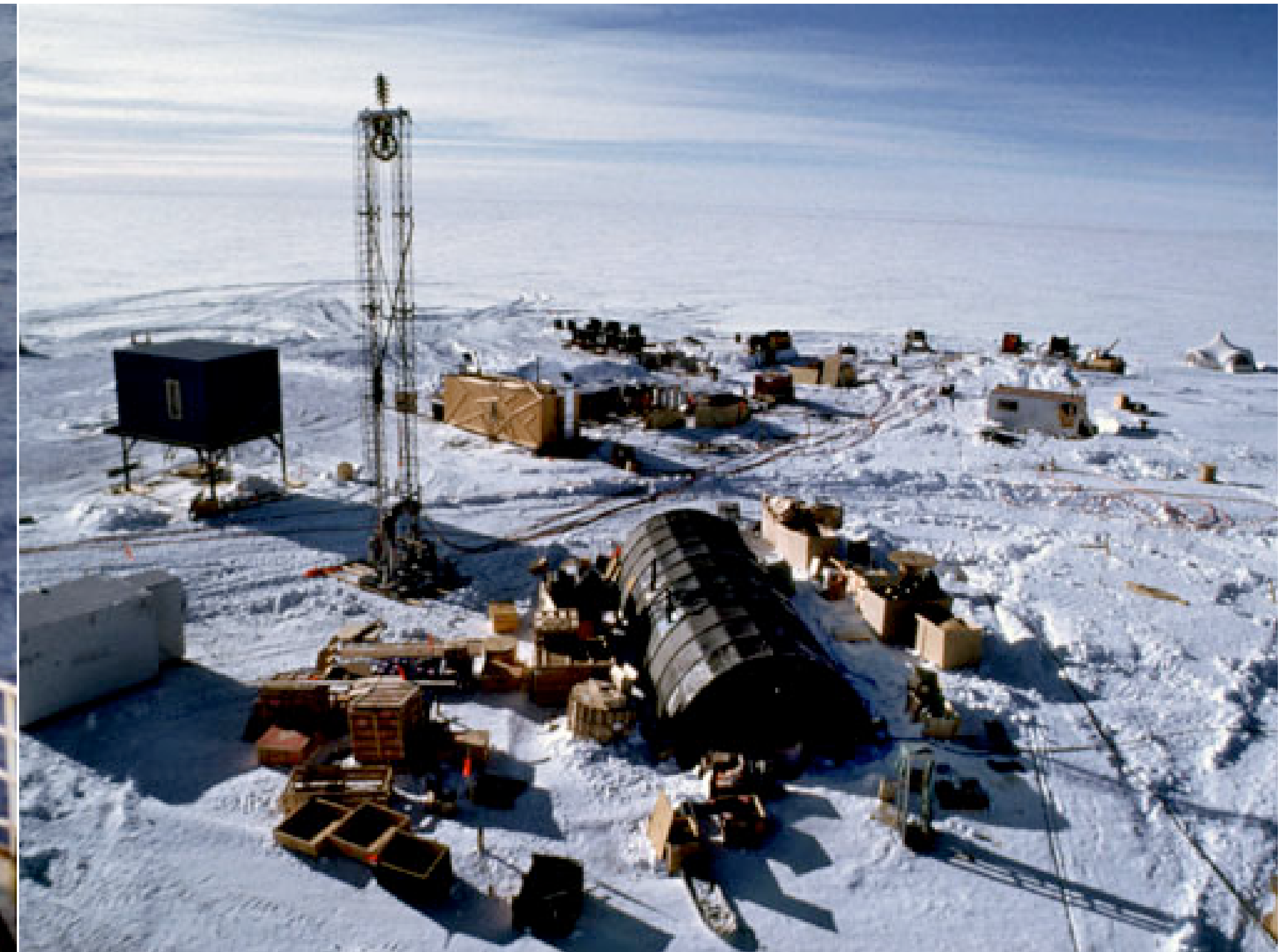
Multi-messenger neutrino astronomy.

MeV range covered by the detection of neutrinos from SN 1987A
GeV-TeV atmospheric neutrinos detected (SK, AMANDA II, Baikal)
PeV-EeV limits: Detection of radio pulses (RICE, GLUE, FORTE)
Extensive air showers (AGASA, Fly's Eye, HiRes,Auger)

TeV-PeV Underwater/ice Cherenkov detectors (Icecube (+), ANTARES)
PeV-EeV Radio detectors (ANITA, ARIANNA)
Ultra High Energy Cosmic Ray Air Showers (Pierre Auger)

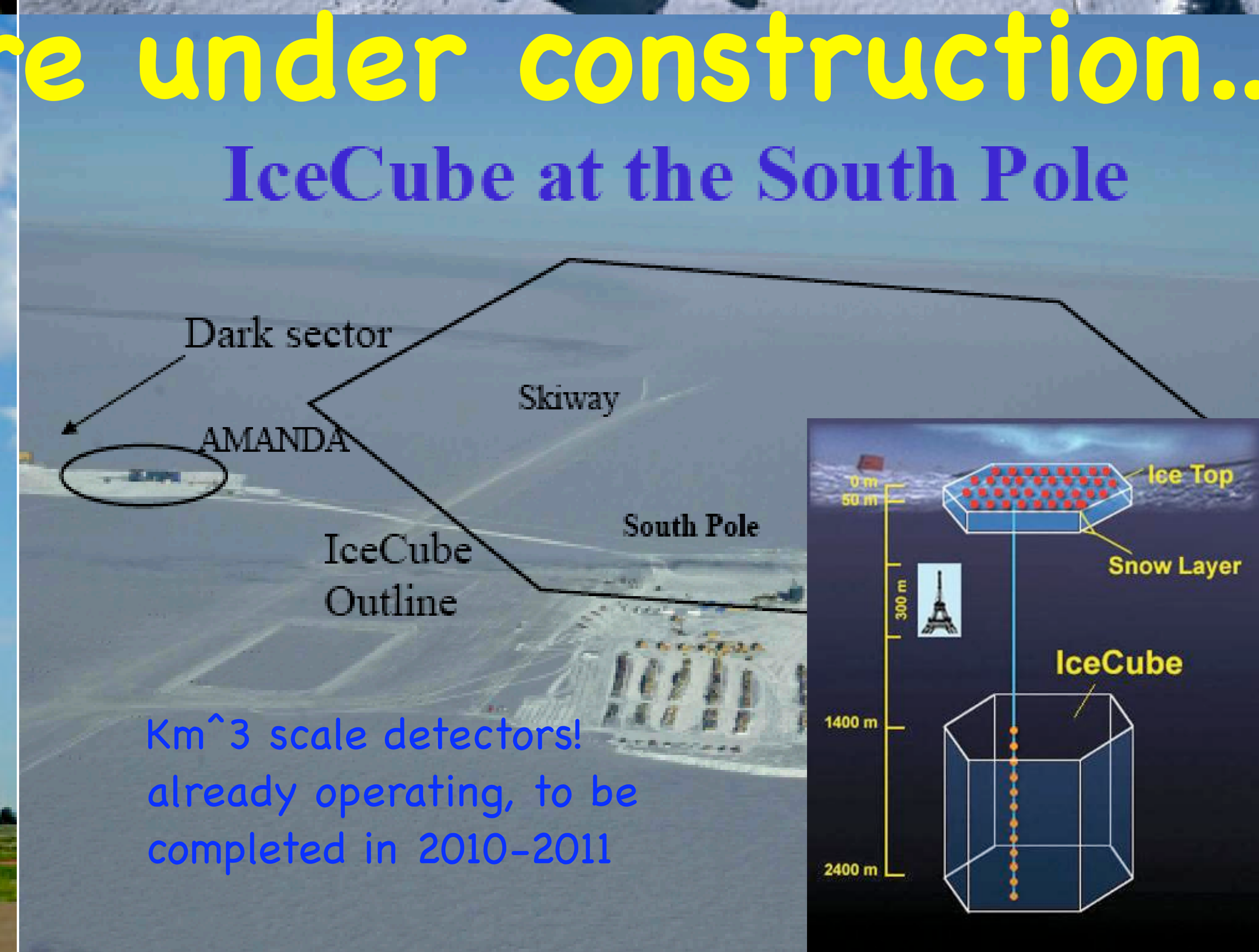
GeV Gamma Ray detectors (GLAST)





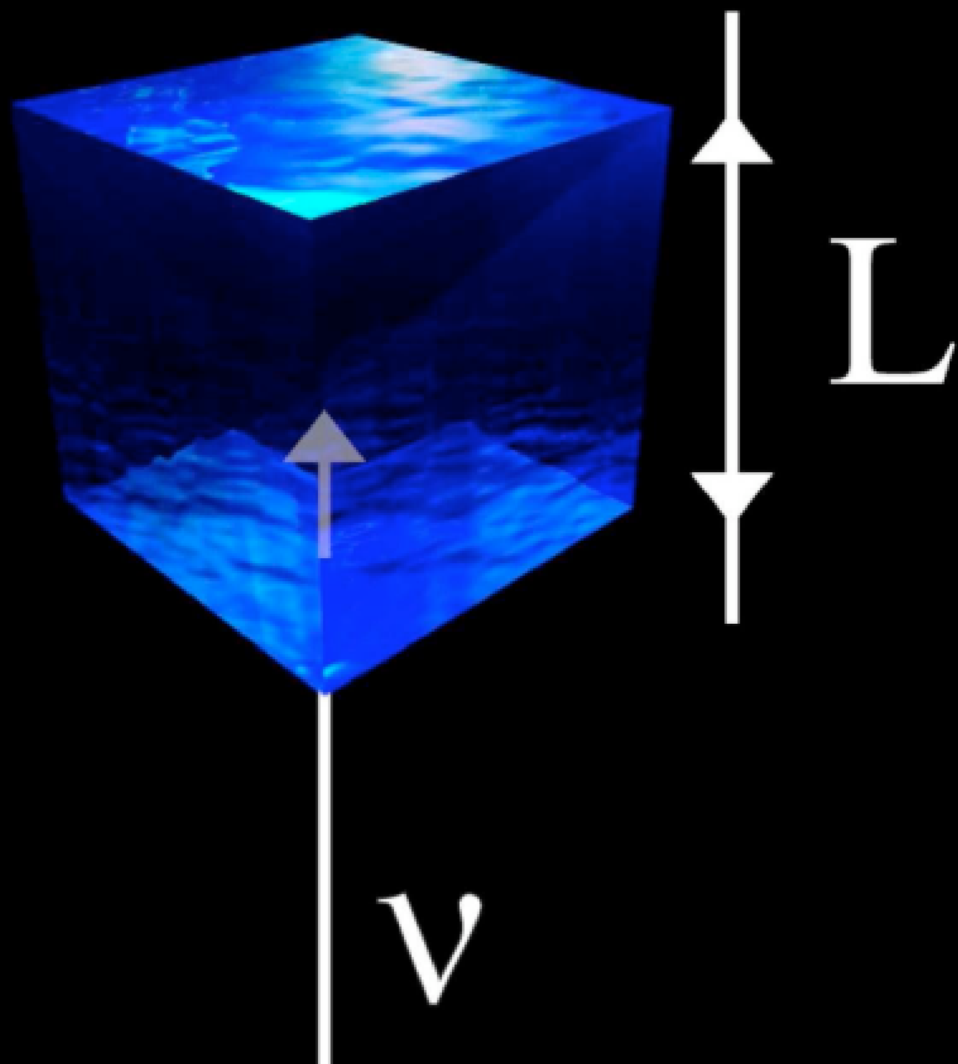
Awesome detectors are under construction...

This field has NOW entered into a very interesting era: new windows into Physics, Astrophysics and Cosmology!



Km^3 scale detectors! already operating, to be completed in 2010-2011

THE ICECUBE NEUTRINO OBSERVATORY



Cherenkov radiation from secondaries

Neutrino energy threshold: hundred GeV

80 strings, 60 OM per string

(4800 optical modules in total)

8 strings already completed!

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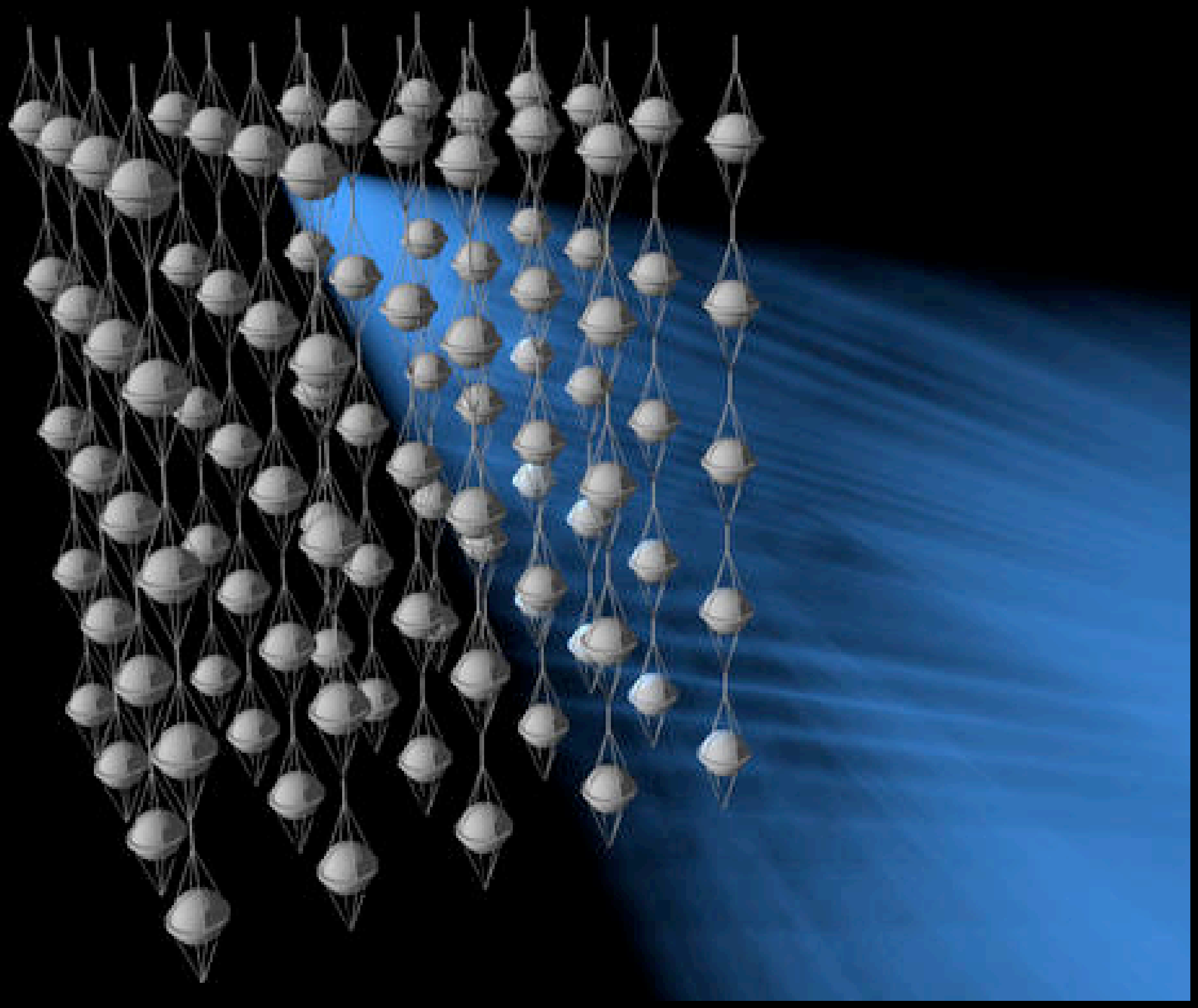

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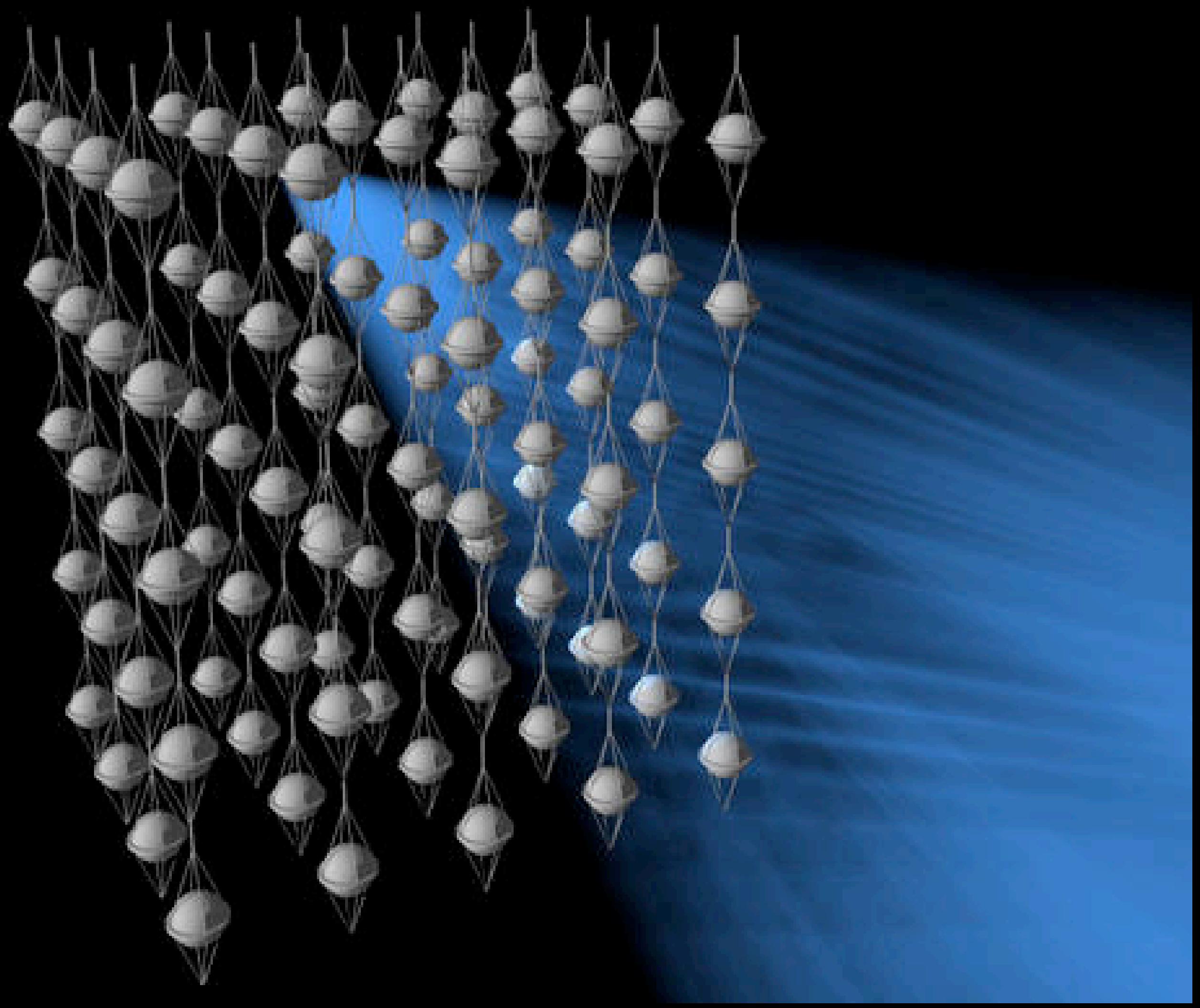

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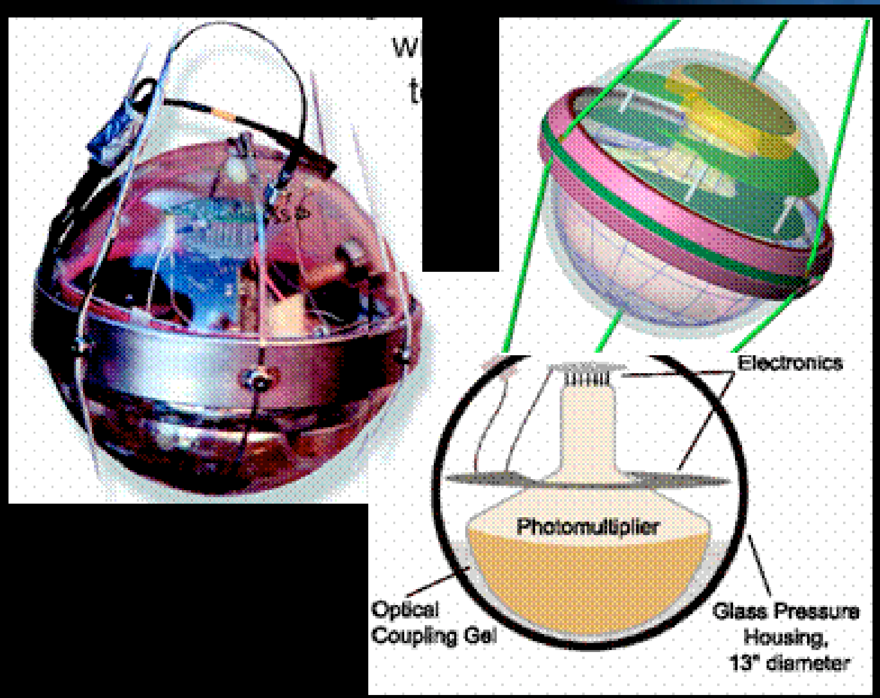

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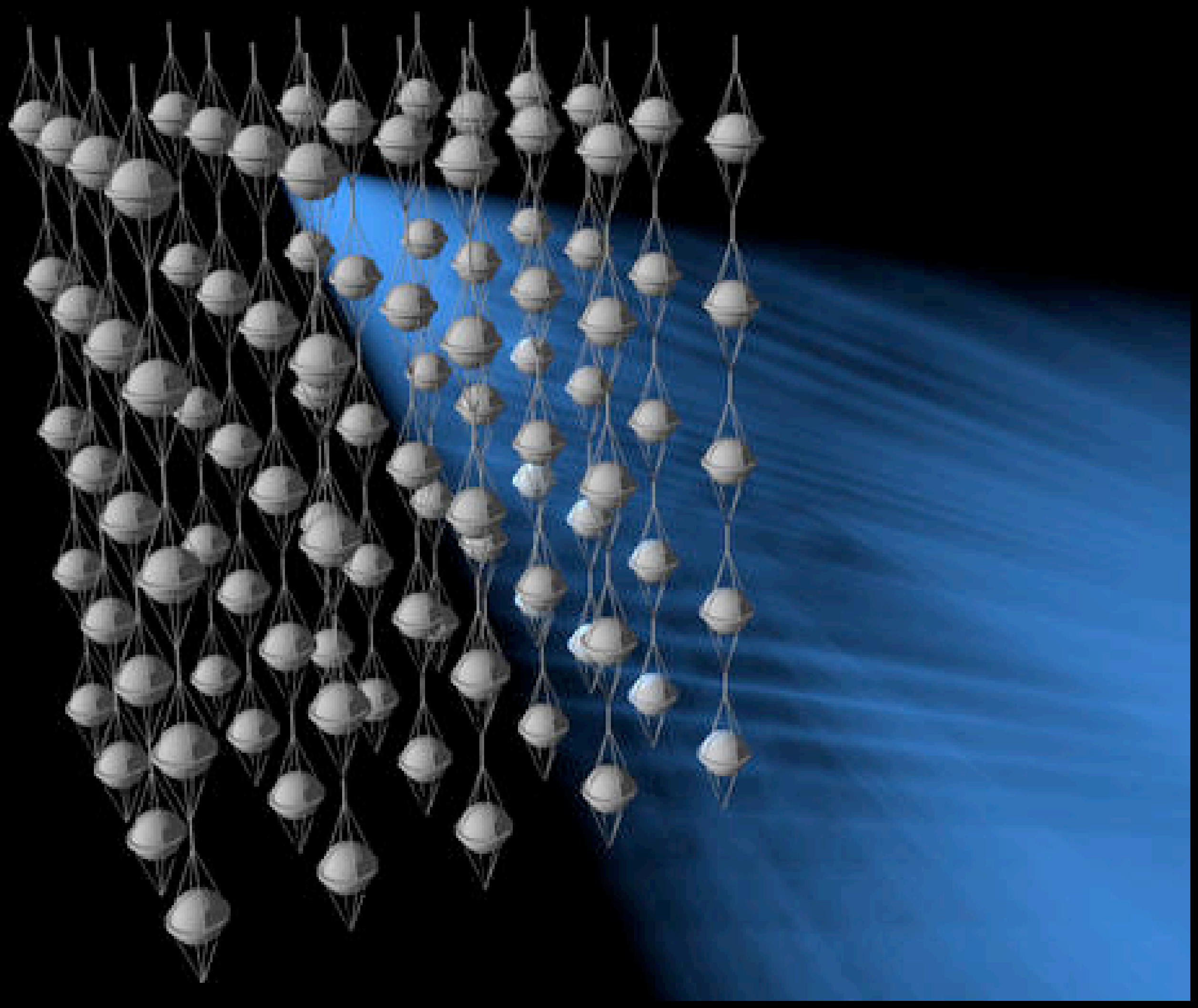

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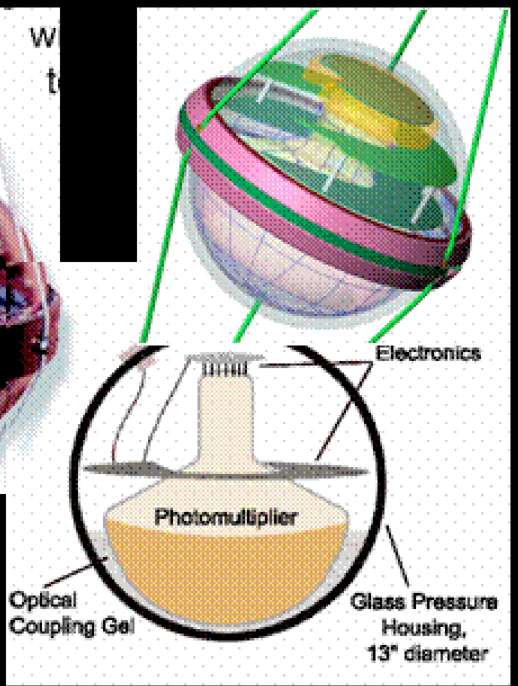
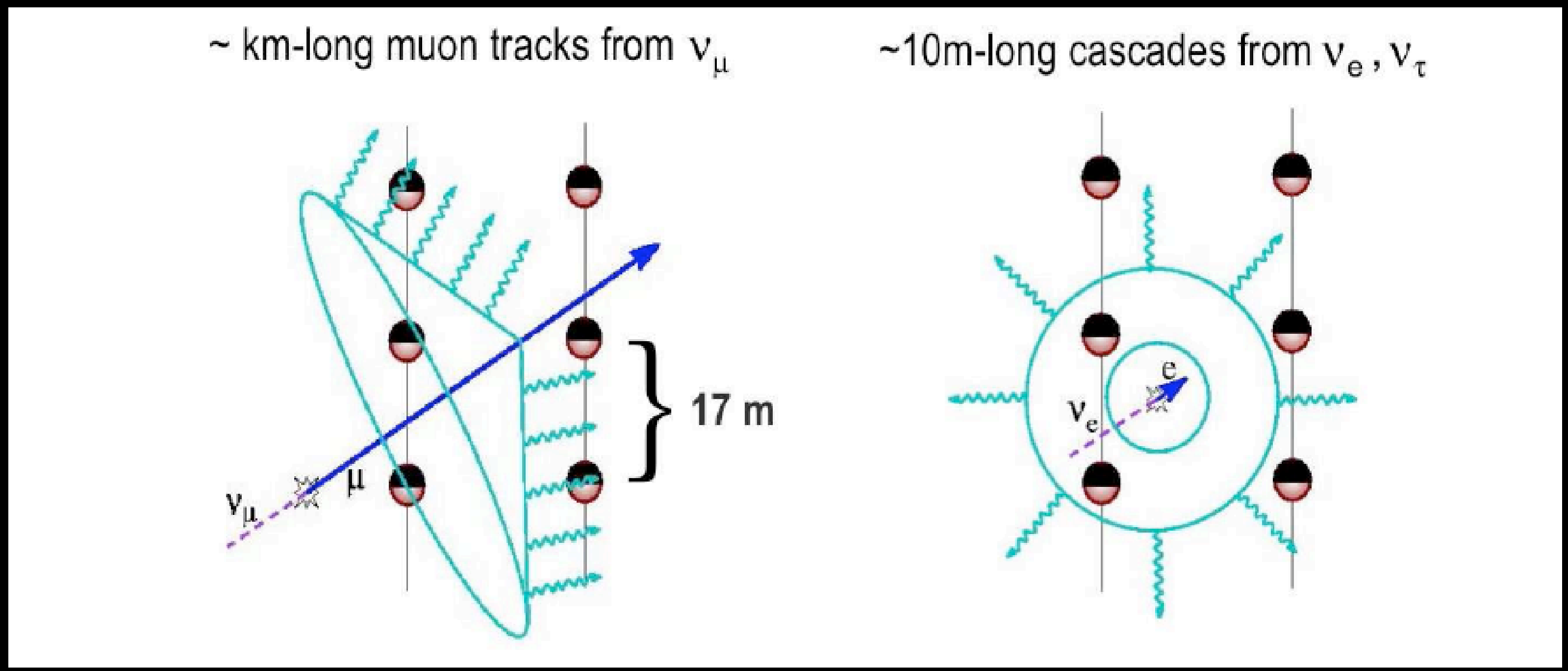




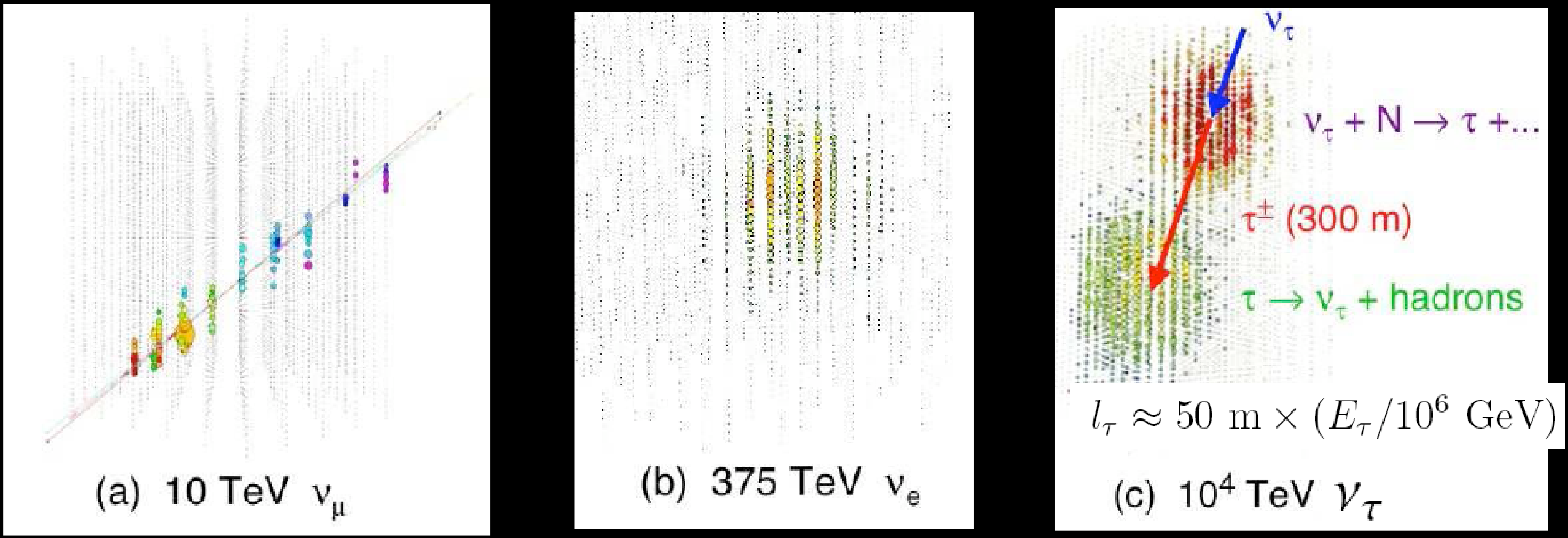
Measuring flavor ratios of HE neutrinos

Beacom, Bell, Hooper, Pakvasa & Weiler, PRD'03

1) Muon tracks
2) Showers (CC interactions of electron and tau neutrinos plus NC interactions of all flavors)
3) "Double bang" events of tau neutrinos

1) Muon tracks are easy, especially at lower energies (for energy reconstruction purposes)
   Energy resolution: dlog E = 10%. Angular resolution: 0.7 degrees
2) Showers are harder to measure: higher energy threshold, smaller size
   Energy resolution: dlog E = 10%. Angular resolution: 10 degrees
3) Tau neutrino "double" signature only above 1 PeV. Really hard to get large statistics.

Shower-to-muon track ratio expected to be measured with "good" accuracy!



(a) 10 TeV ν_μ (b) 375 TeV ν_e (c) 10^4 TeV ν_τ

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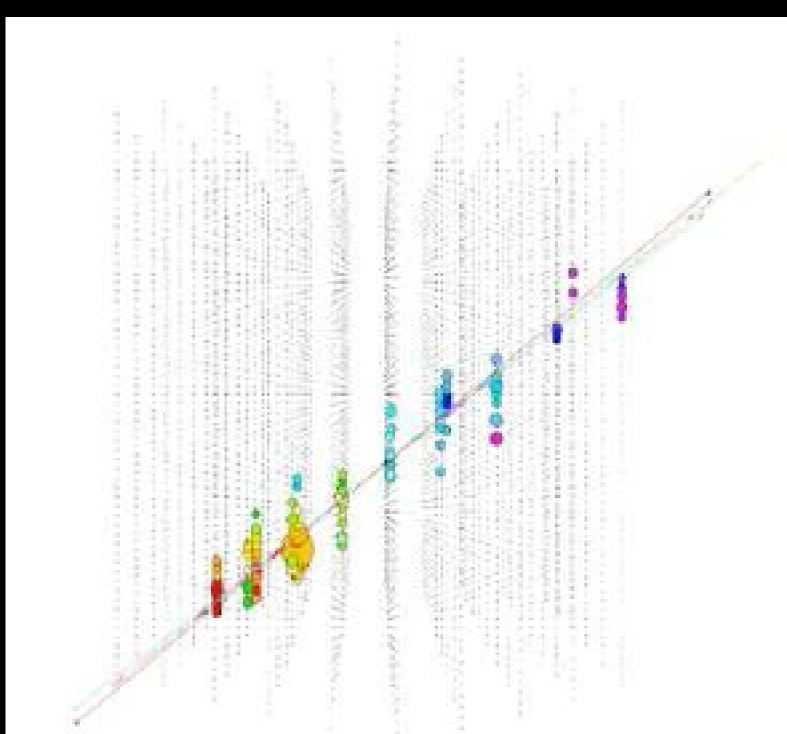
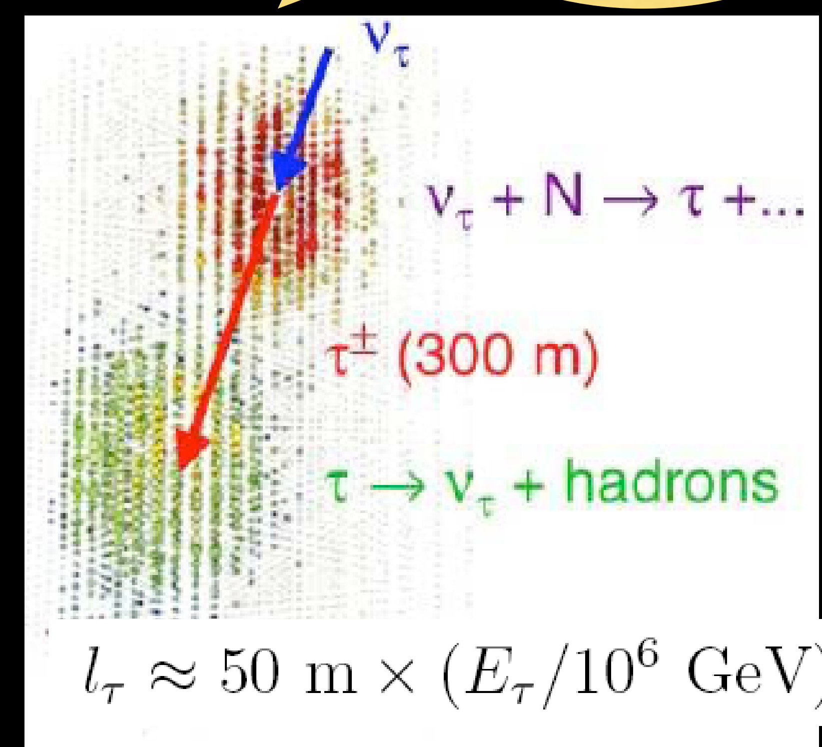


(a) 10 TeV ν_μ

(b) 375 TeV ν_e



(c) 10^4 TeV ν_τ

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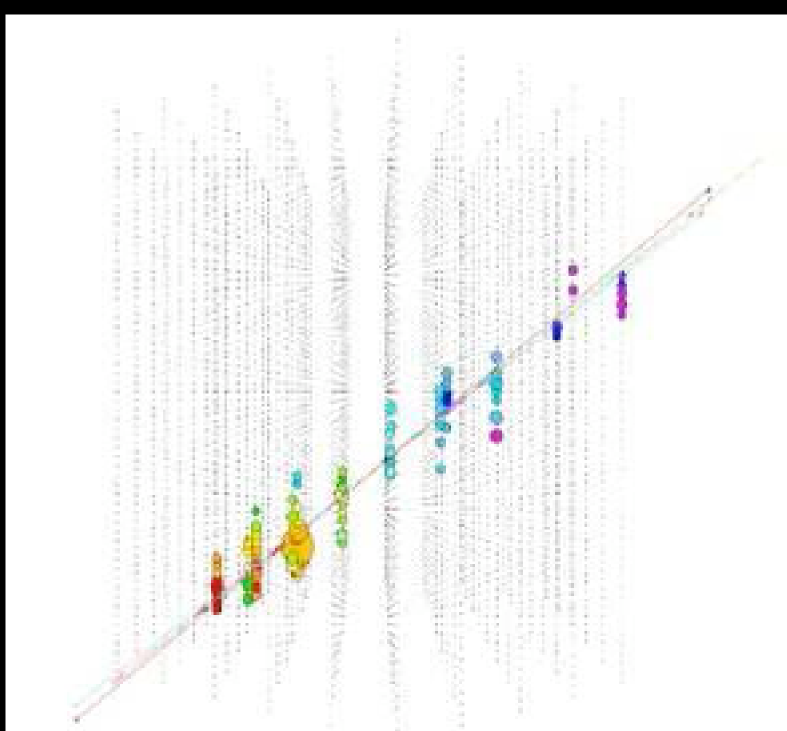
Interesting!
even for a theorist
muon, electron and
tau neutrino events
DO look different!!

Shower-to-muon track ratio expected to be measured with "good" ac



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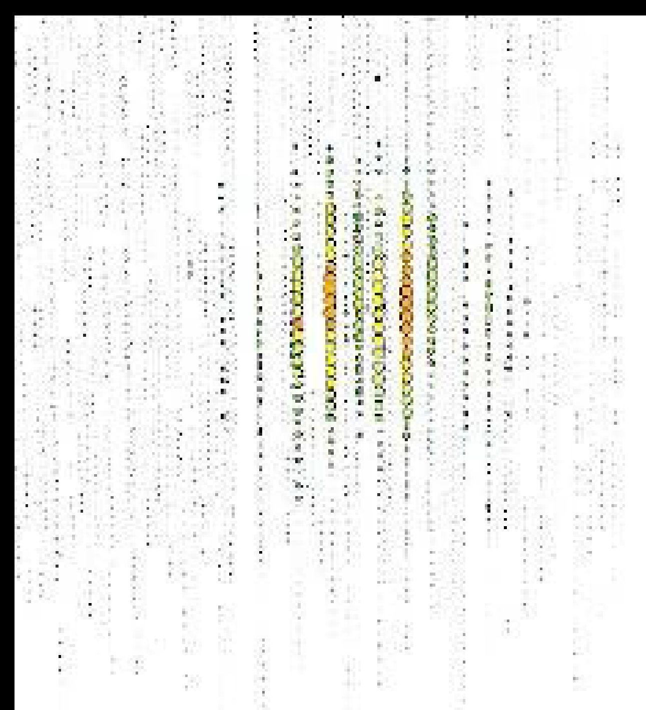
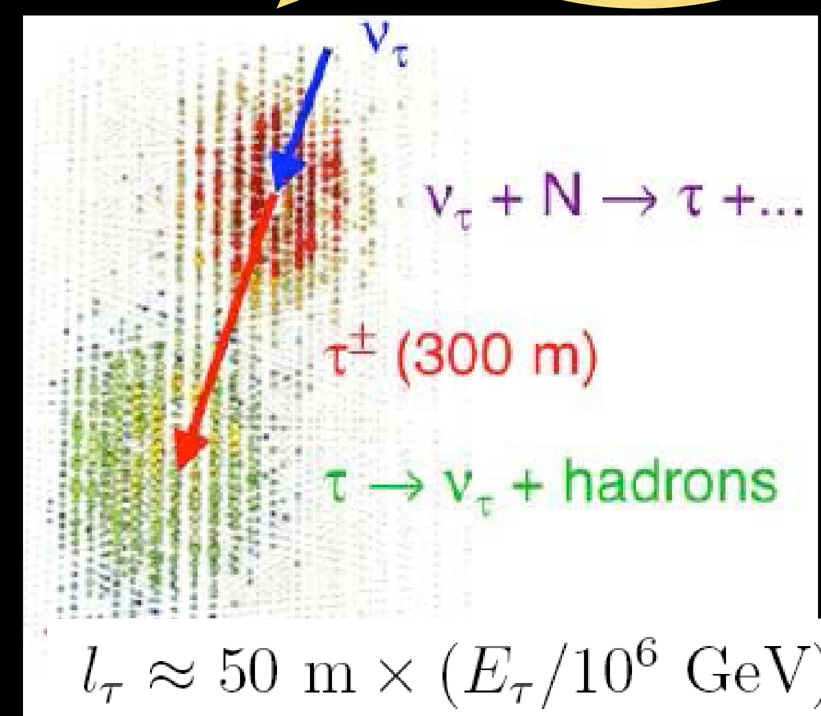
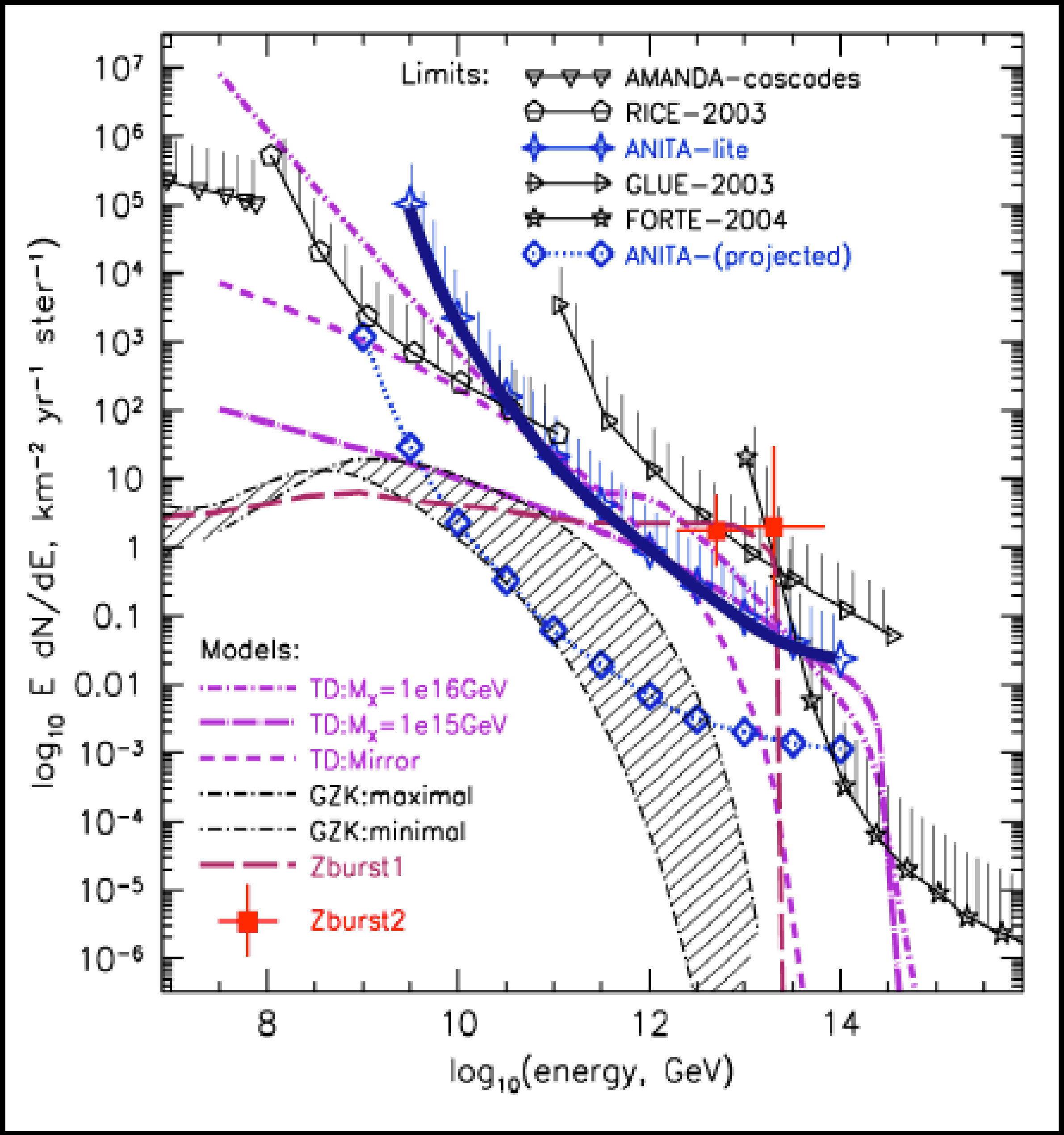


(b) 375 TeV ν_e

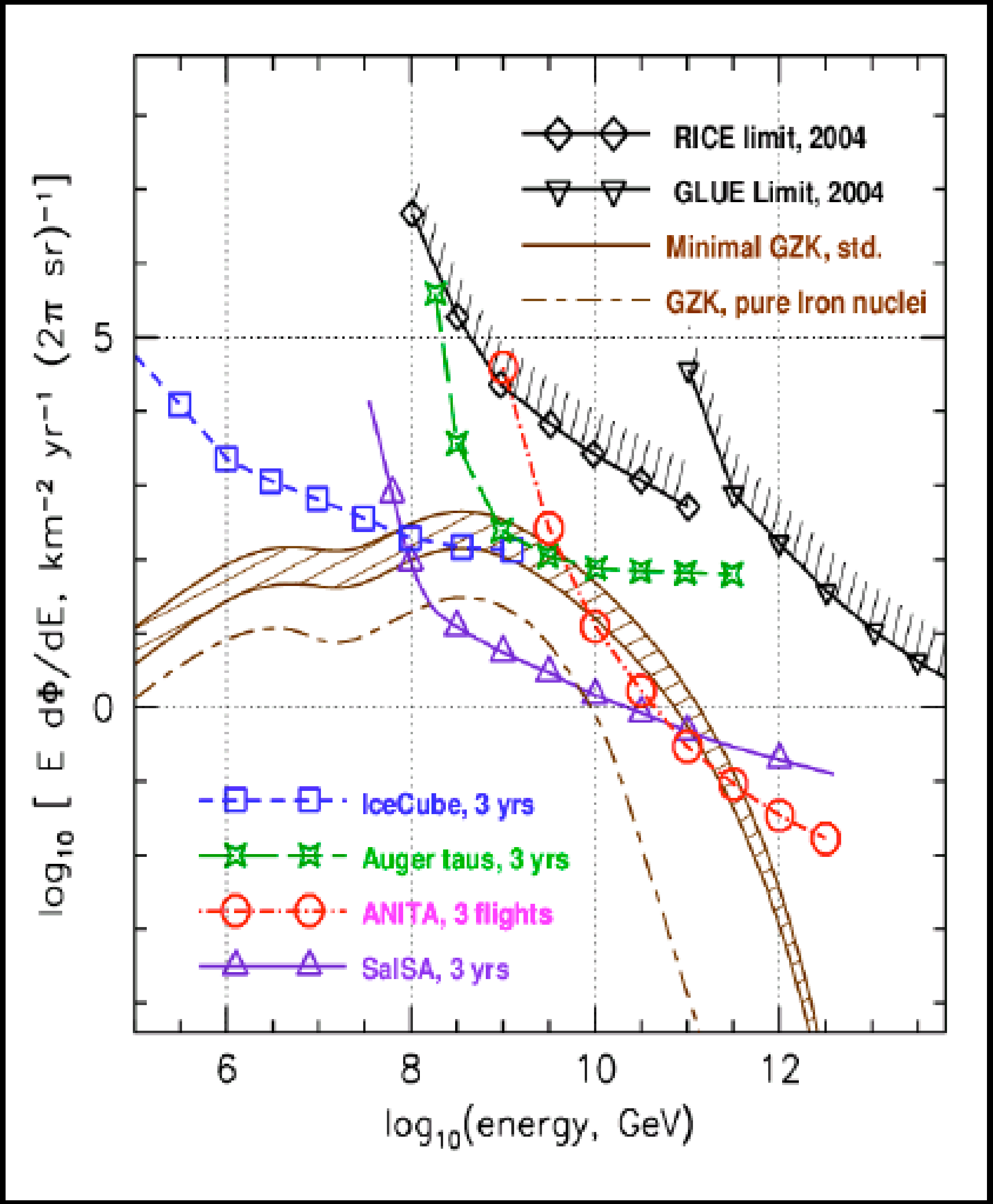


(c) 10^4 TeV ν_τ

Present



Future

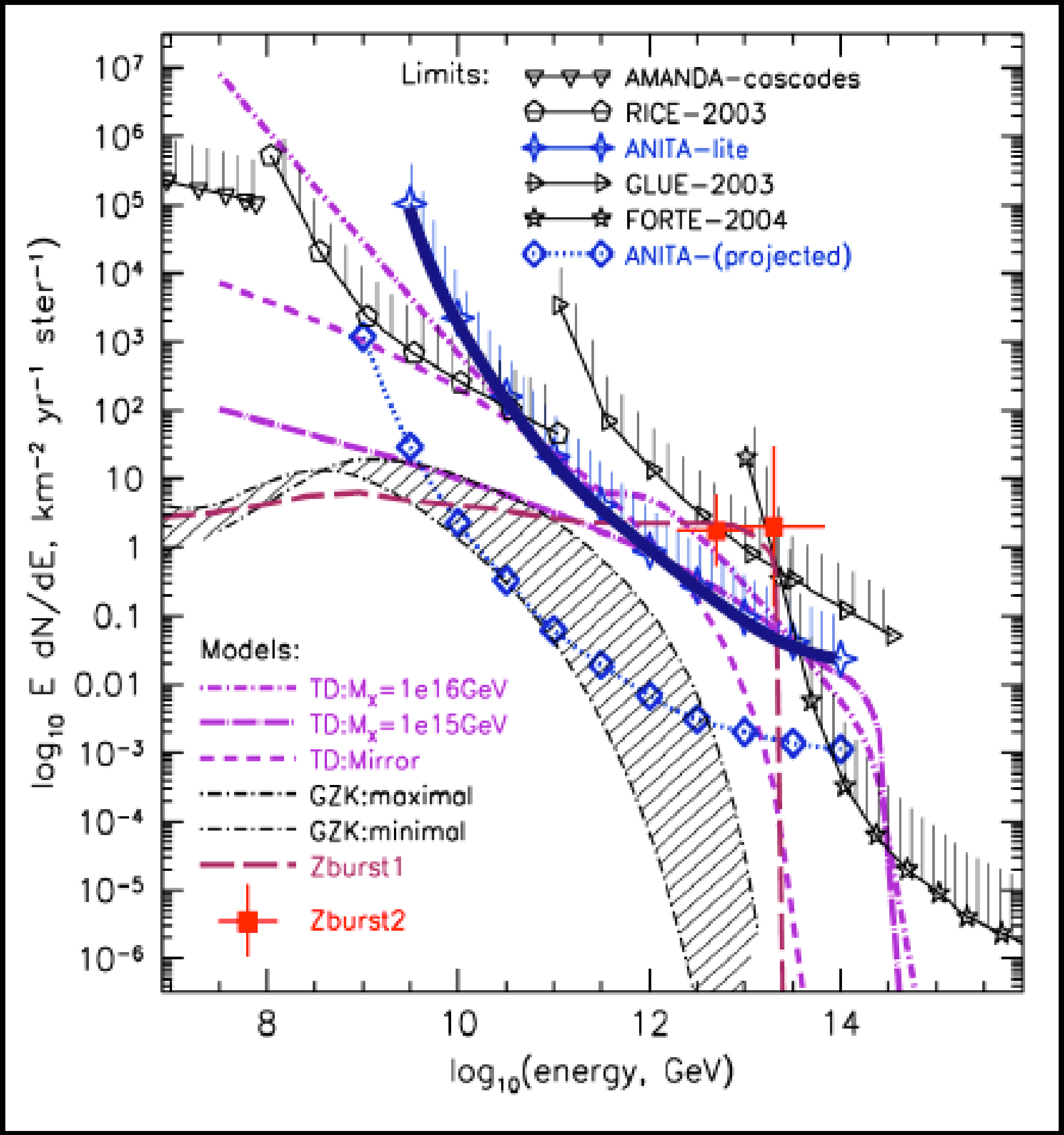


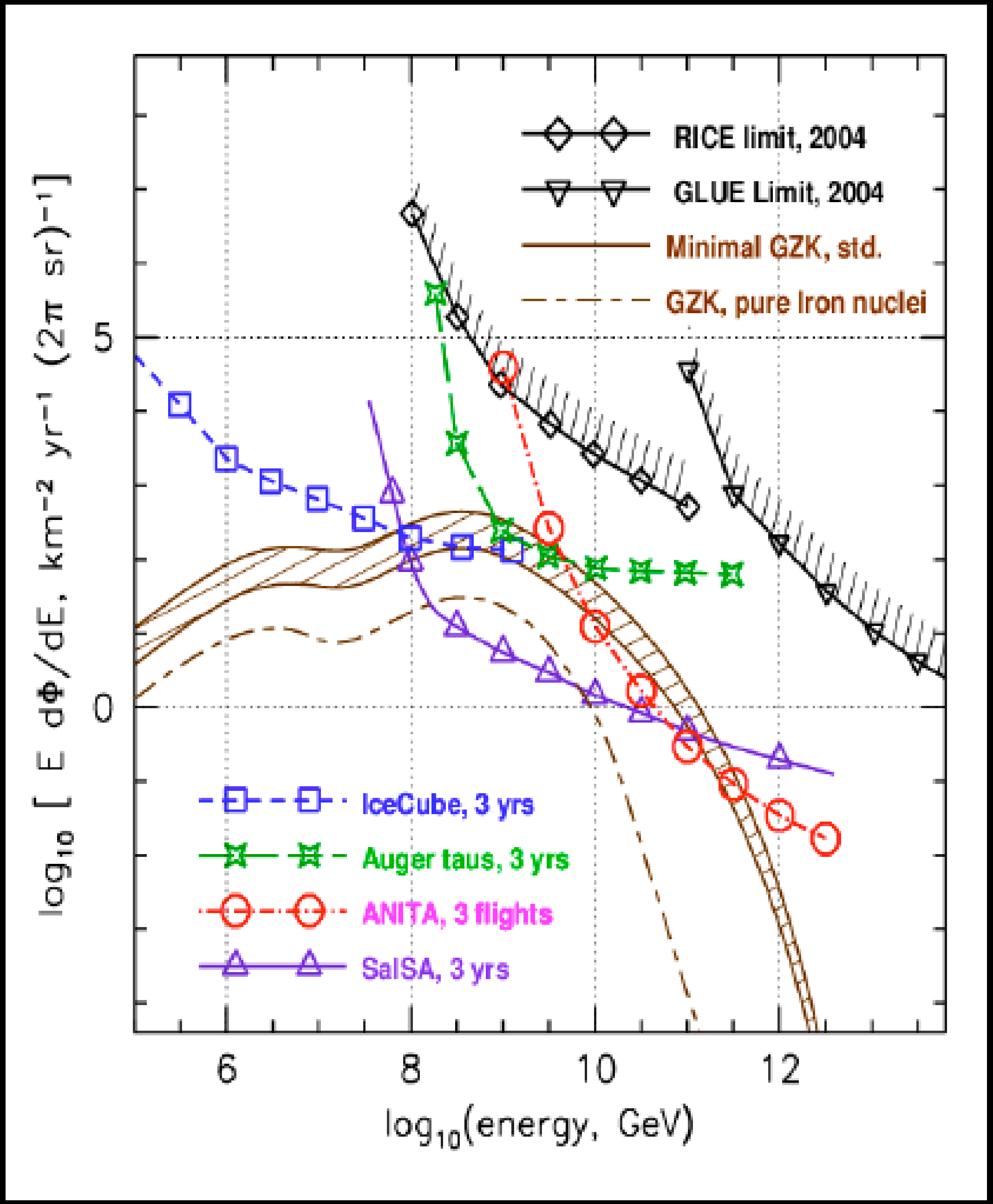
"Constraints on Cosmic Neutrino Fluxes from the ANITA Experiment"

Barwick et. al, PRL'06

Present ?

Future





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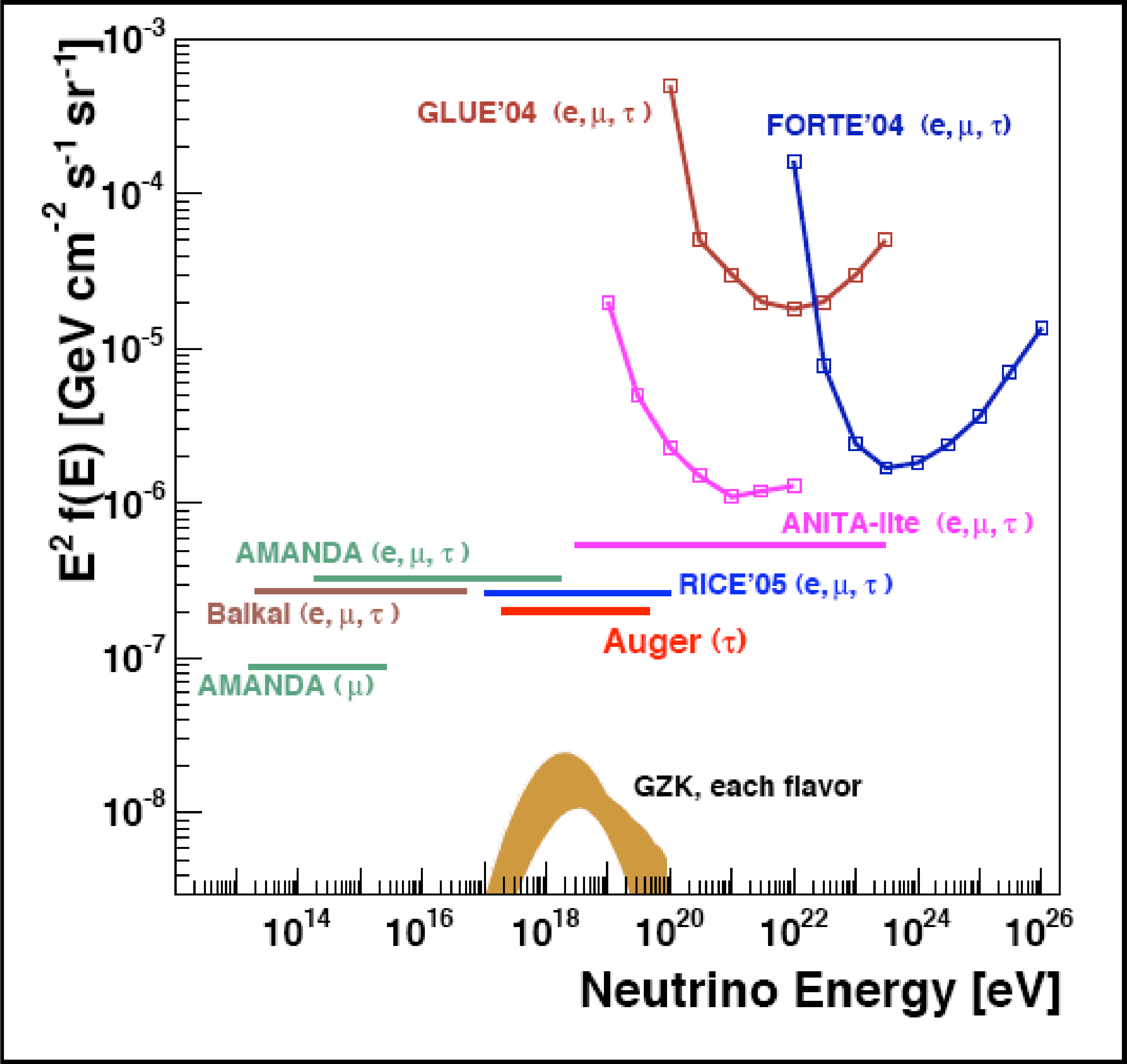

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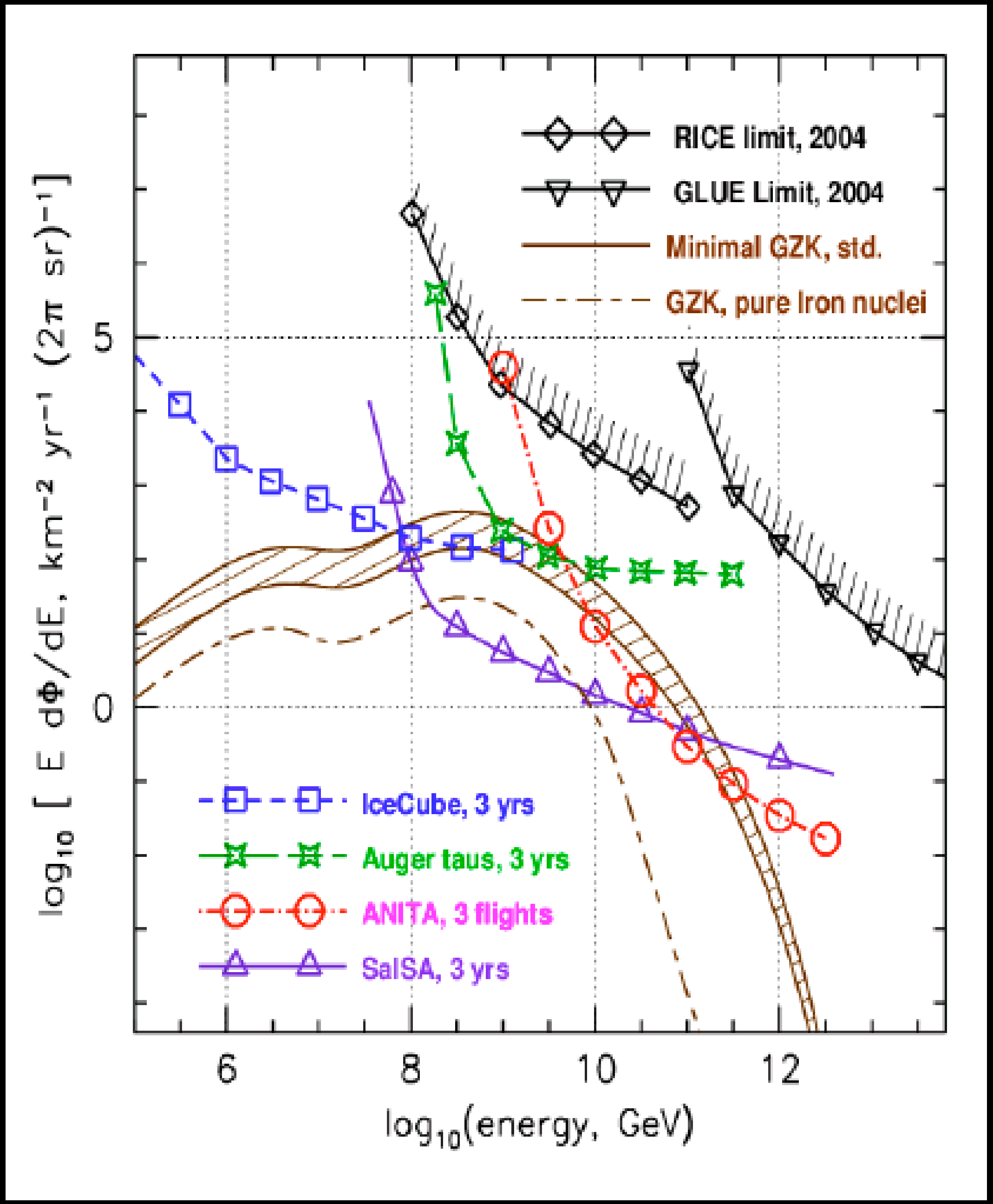


"Limits to the diffuse flux of UHE tau neutrinos at EeV energies from the Pierre Auger Observatory"

June 12th' 07

Standard model prediction for GZK neutrino fluxes = TINY!
< 1 neutrino event per km^2 per day,
0.5 muon events per year per cubic km of water or ice....

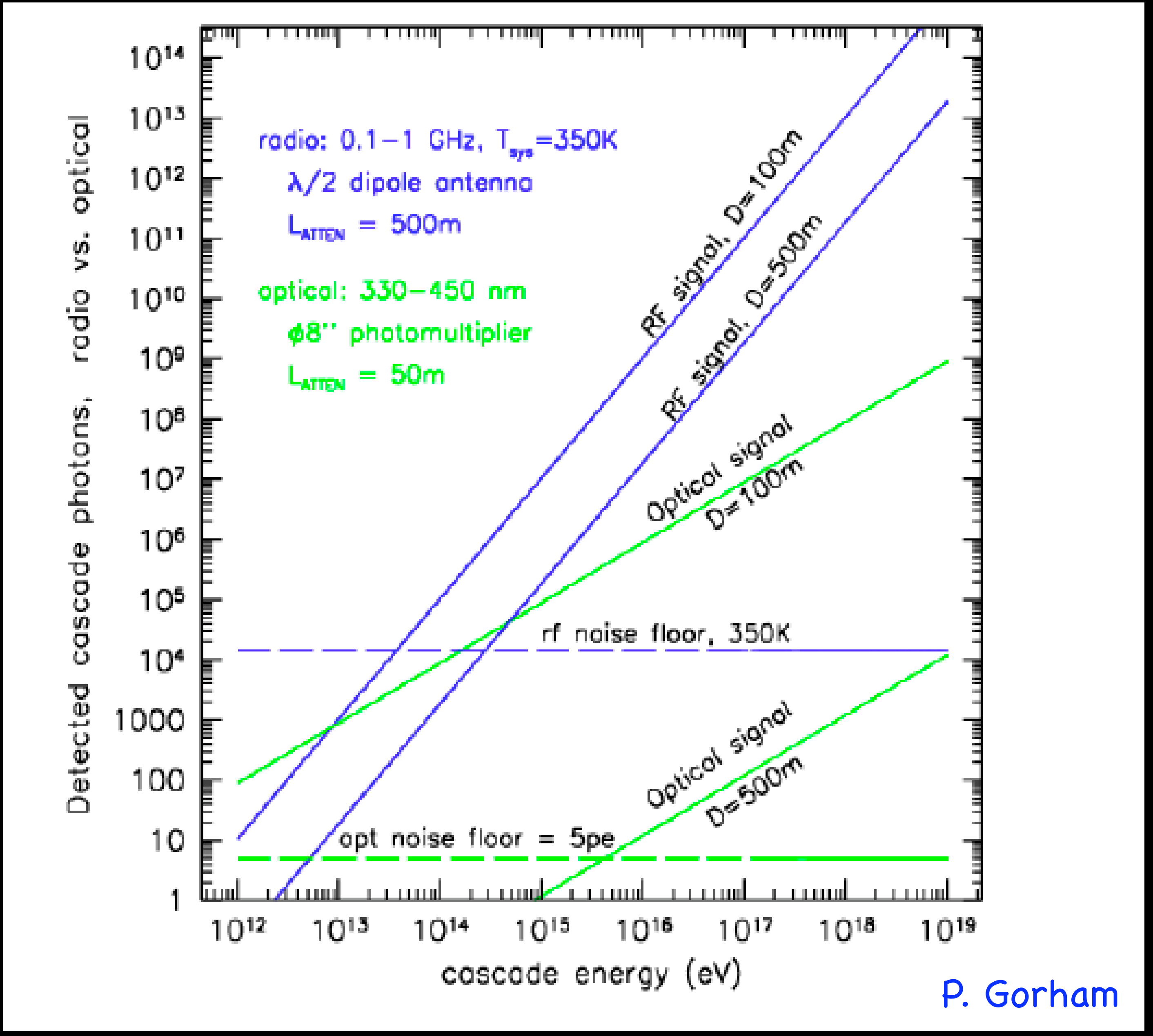
How can we scale "current" ice/water Cherenkov detectors?

RADIO VS OPTICAL CHERENKOV DETECTION

Askaryan (1965) noticed that STRONG COHERENT RADIO CHERENKOV EMISSION could occur from a negative charge excess in a shower propagating within a dielectric.

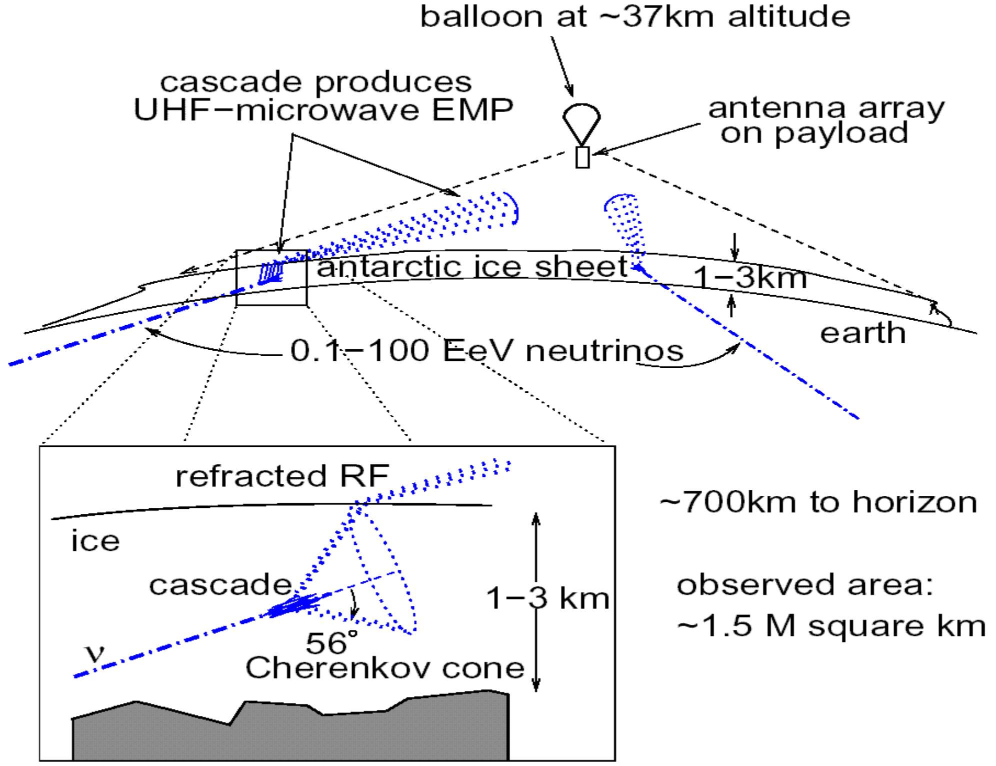
In the fully coherent regime, RF signal grows quadratically with shower energy, dominates above PeV!

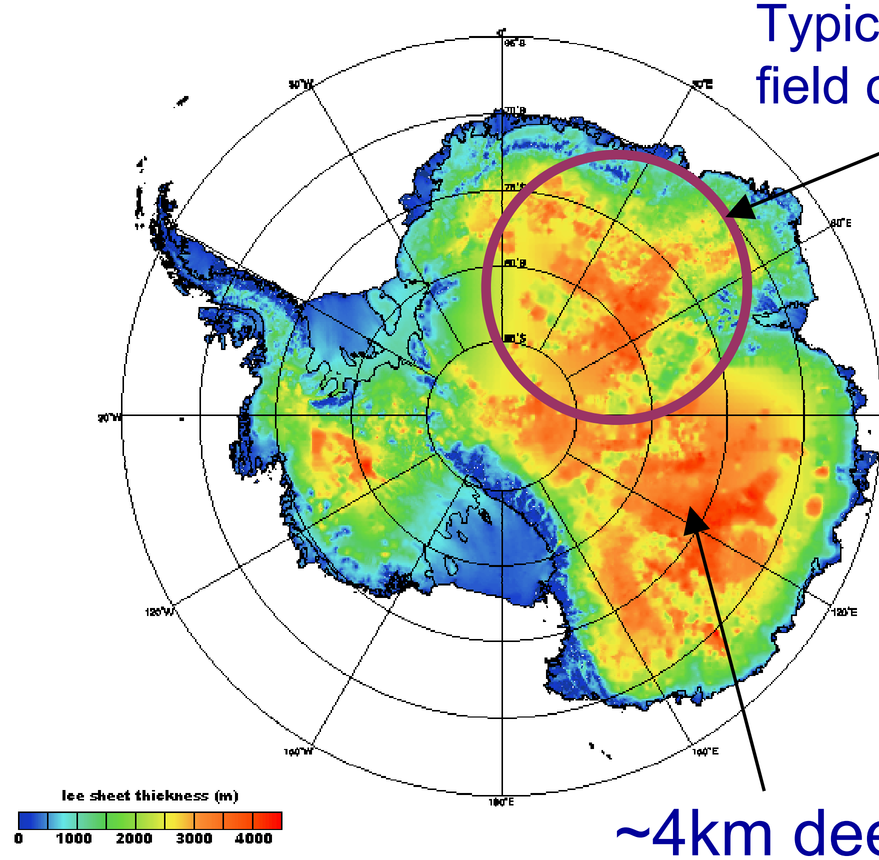
The moon surface (GLUE),
ice (FORTE, RICE,ANITA, ARIANNA),
rock-salt...
are possible radio-clear media
where neutrino can shower



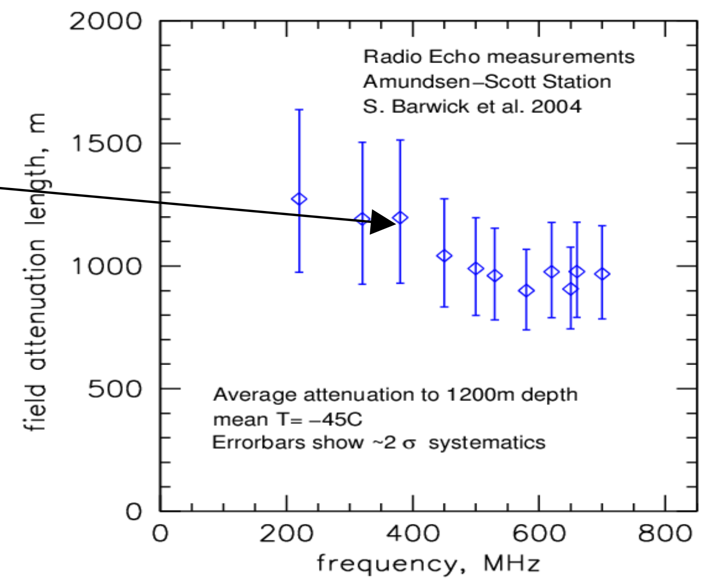
P. Gorham

ANITA concept





Ice RF clarity: 1.2 km(!) attenuation length



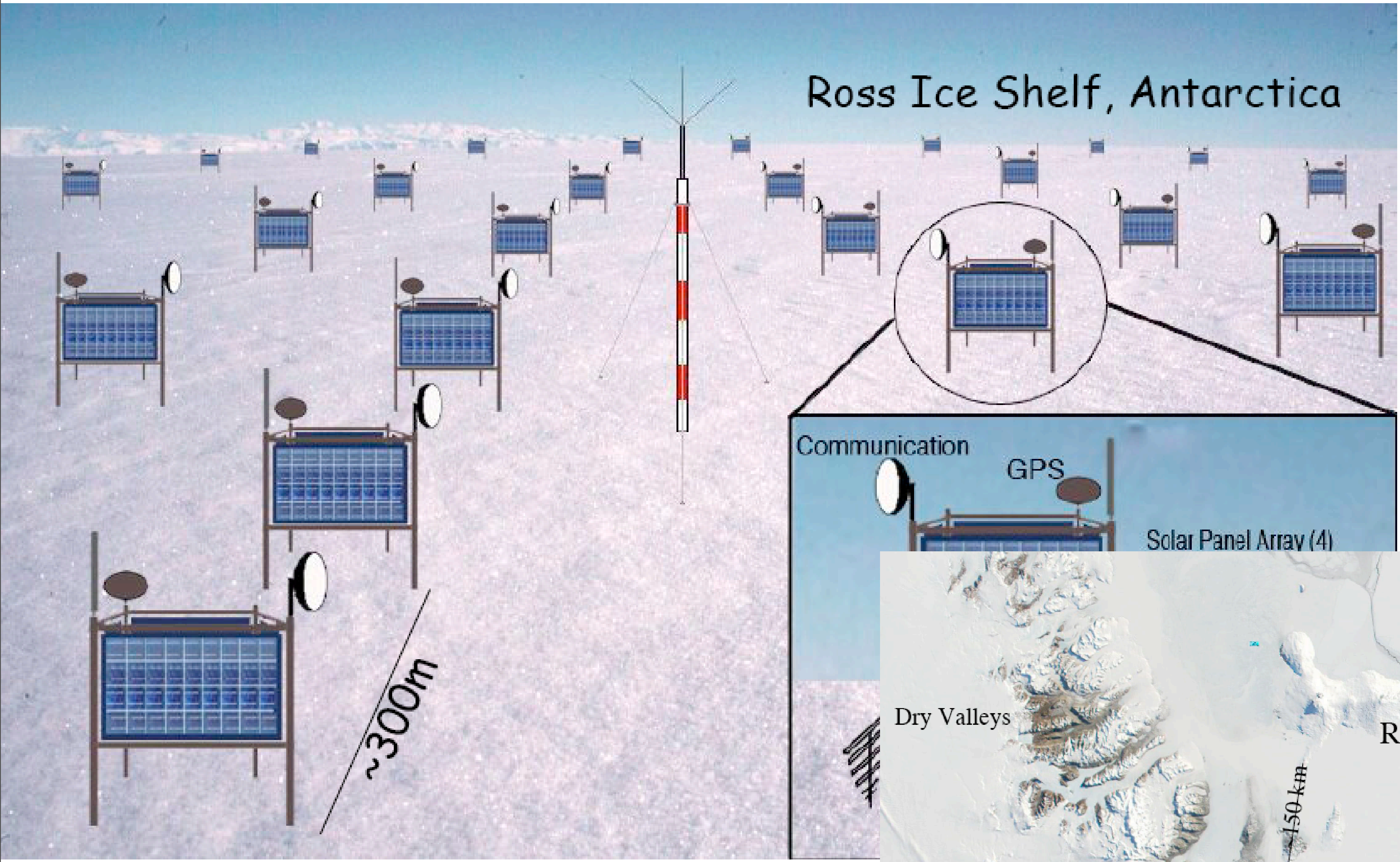
Effective "telescope" aperture:

- ~250 km^3 sr @ $10^{18.5}$ eV
- ~10^4 @ km^3 sr 10^{19} eV

Area of Antarctica ~ area of Moon!

ARIANNA Concept

100 x 100 station array, ~1/2 Teraton

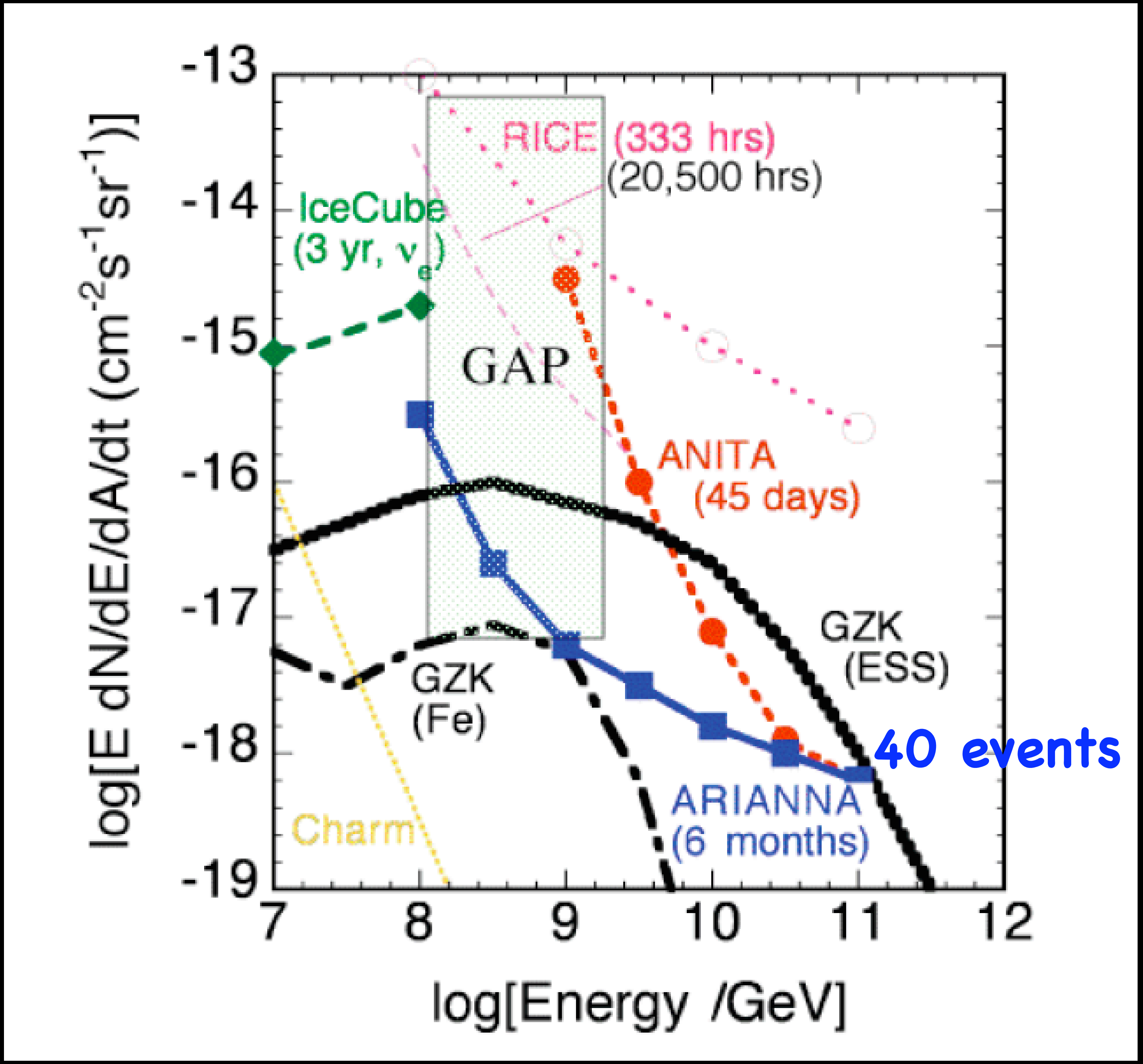


S. Barwick, talk May 2007

RADIO CHERENKOV DETECTORS: ANITA, ARIANNA

Just to detect ANY of them: Big breakthrough!

After: Identifying sources!



S. Barwick,
talk May 2007

Sources?

1) **Flavor** composition (mostly coming from pion decays)

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\downarrow$$
$$e^+ + \bar{\nu}_\mu + \nu_e$$
$$\Rightarrow \nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$$

2) **Energy** distribution

3) **Normalization** (correlation with photons, protons)

4) **Source distribution** (pointing?)

Sources?

1) Flavor composition. NOT ALWAYS:

$$\nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$$

a) Neutron decay

Galactic point-sources of electron antineutrinos

(Anchordoqui, Goldberg, Halzen & Weiler, PLB'04)

If there exists regions (Cygnus) in which the Cosmic Rays primaries are NEUTRONS, neutrons with energies higher than 1 EeV will decay in flight, producing a flux of TeV electron antineutrinos:

$$n \longrightarrow p + e^- + \bar{\nu}_e$$

Canadian Galactic Plane Survey

Sources?

1) Flavor composition. NOT ALWAYS:

$$\nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$$

a) Neutron decay

$$\nu_e : \nu_\mu : \nu_\tau = 1 : 0 : 0$$

b) Energy-dependent flavor ratios:

Energy thresholds, muon energy losses (at energies > 100 TeV)

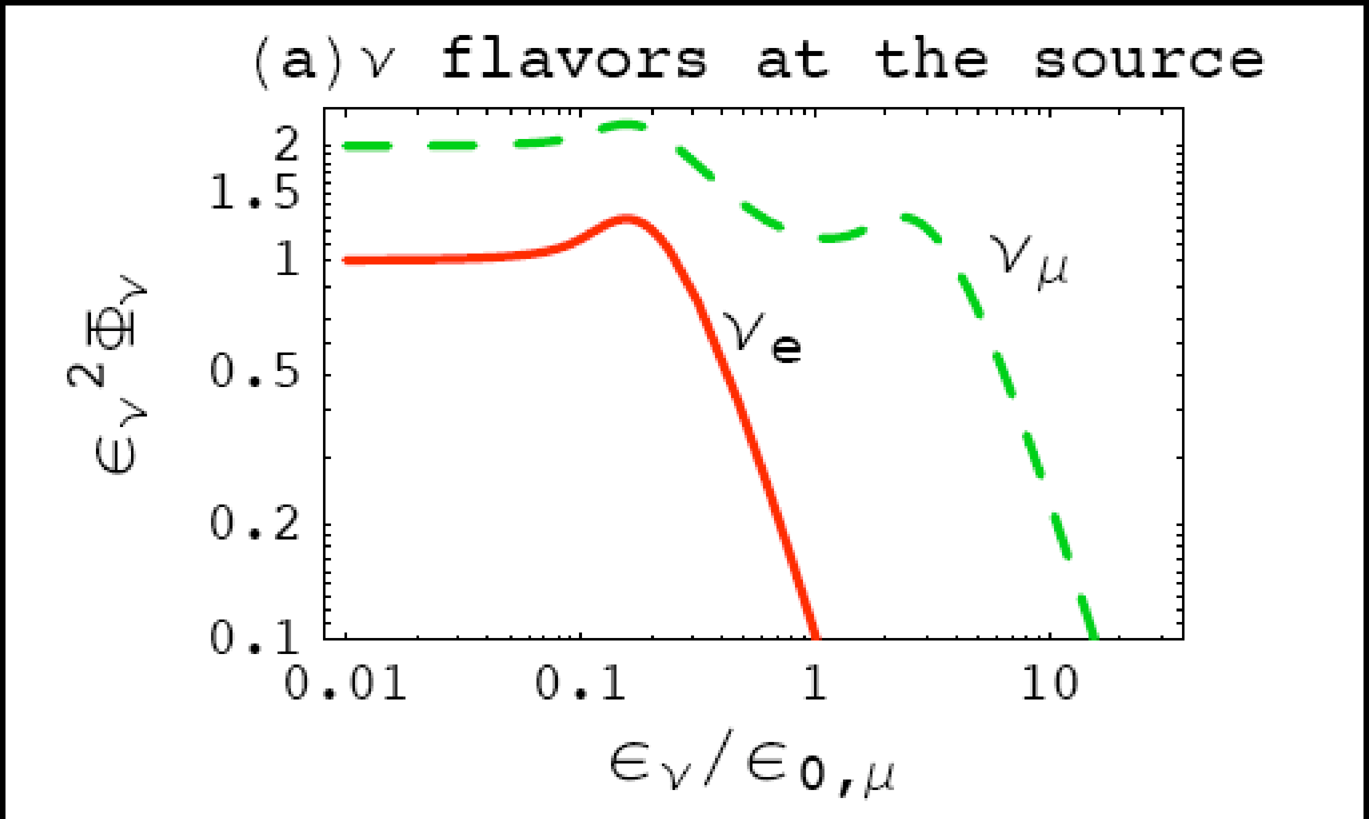
(Rachen & Meszaros, PRD'98, Kashti & Waxman, PRL'95, Kachelriess & Tomas, PRD'06)

Flavors depend on the energy

(Kashti & Waxman, PRL'95)

Pions are produced in environments in which they can loose energy due to interaction with radiation and magnetic fields. At high energies, the muon energy losses before decay affect the neutrino composition.

Suppression at high energies of the relative contribution of muon decay to the neutrino flux!



$$\pi^+ \rightarrow \mu^+ \nu_\mu$$
$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$

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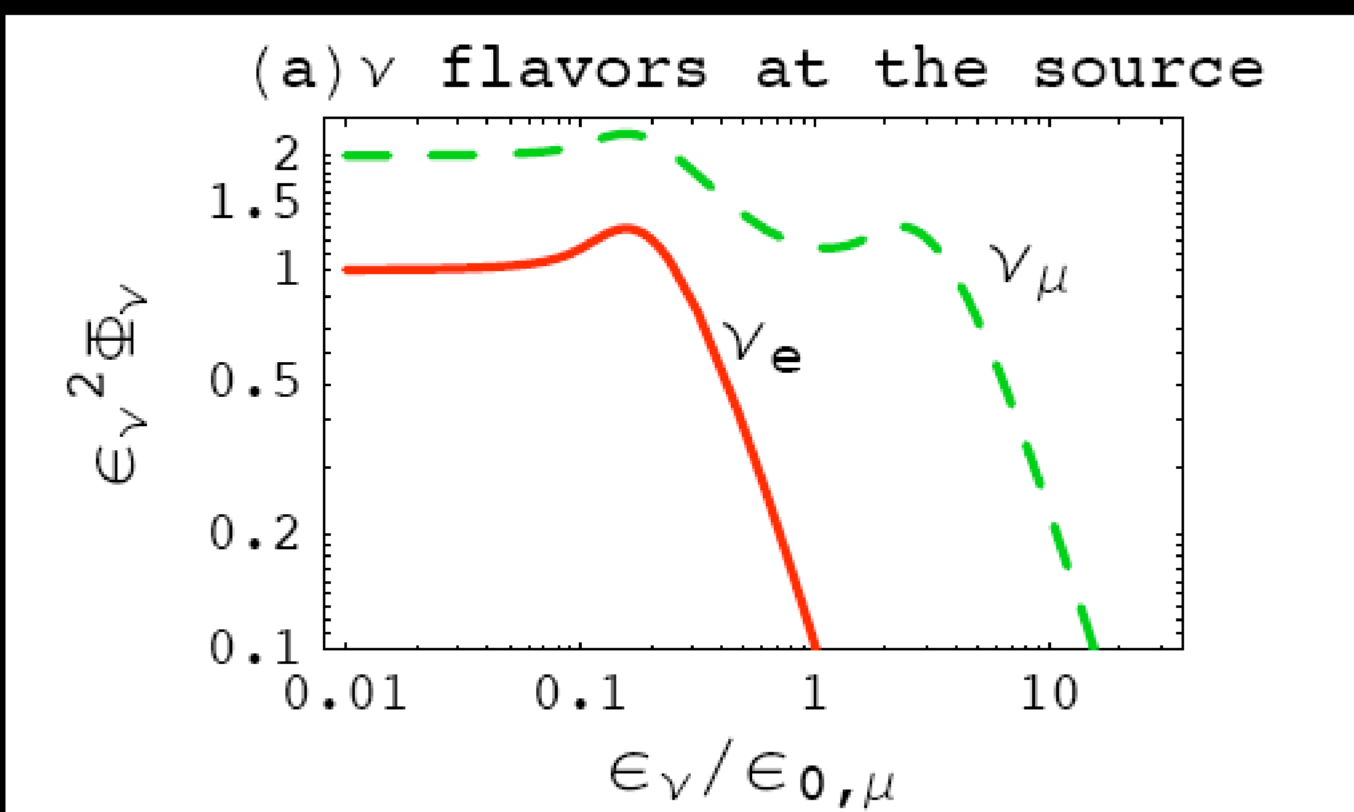

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$$\nu_e : \nu_\mu : \nu_\tau = 0 : 1 : 0$$

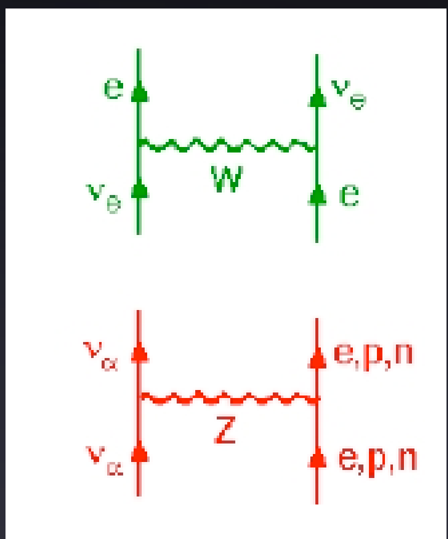
c) Matter effects inside the astrophysical source?

(with Irina Mocioiu and Soeb Razzaque, PRD'07)

Matter effects

Wolfenstein'78, Parke'86, Parke &Walker'86, Mikheyev & Smirnov'89

When neutrinos travel through the interior of the Sun, Supernova, Earth



$$i\frac{d}{dt}\begin{pmatrix}\nu_e\\ \nu_\mu\end{pmatrix} = \begin{pmatrix} -\frac{\Delta m^2}{4E}\cos 2\theta_0 + \sqrt{2}\,G_F N_e & \frac{\Delta m^2}{4E}\sin 2\theta_0 \\ \frac{\Delta m^2}{4E}\sin 2\theta_0 & \frac{\Delta m^2}{4E}\cos 2\theta_0 \end{pmatrix}\begin{pmatrix}\nu_e\\ \nu_\mu\end{pmatrix}$$

Their effective masses and mixings in matter are modified, neutrino flavor transitions are enhanced!

$$\delta m^2_N = \sqrt{(\delta m^2 \cos 2\theta_\odot - 2\sqrt{2} G_F N_e E_\nu)^2 + (\delta m^2 \sin 2\theta_\odot)^2}$$

$$\sin^2\theta^N_\odot = \frac{1}{2}\left(1 - \frac{(\delta m^2 \cos 2\theta_\odot - 2\sqrt{2} G_F N_e E_\nu)}{\delta m^2_N}\right) \qquad \theta^N_\odot > \theta_\odot$$

Resonant density:

$$\sqrt{2}\,G_F\,N_e = \frac{\Delta m^2}{2E}\cos 2\theta_0$$

Lectures from Stephen Parke at Advanced Summer School in Physics, Mexico'06

Matter effects in sources

(in collaboration with Irina Mocioiu and Soeb Razzaque)

In most sources, the density is too low, there is NOT ENOUGH COLUMN DENSITY: matter effects are NEGLIGIBLE

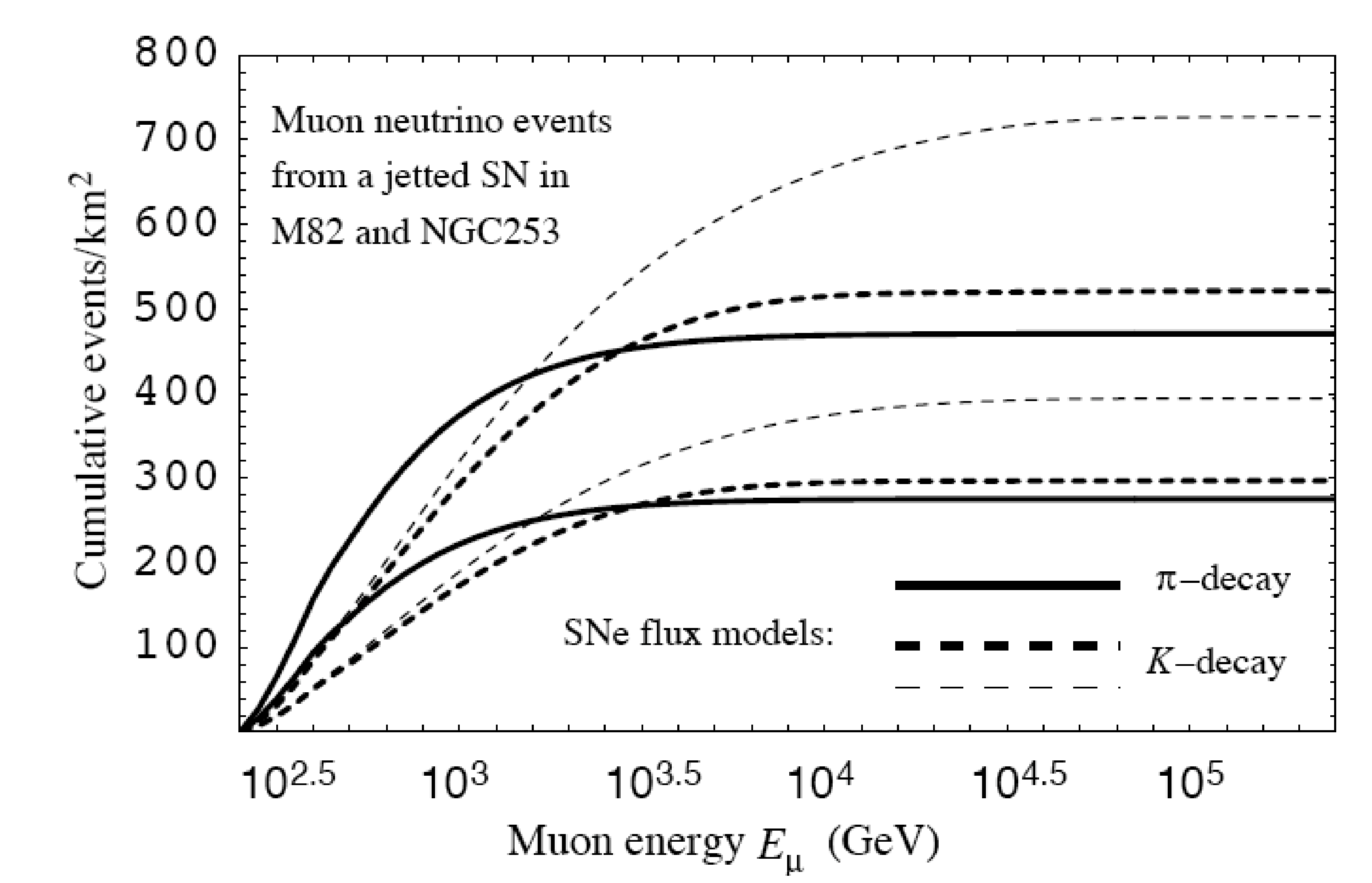
In some sources neutrinos can reach the resonance: SIGNIFICANT MATTER EFFECTS! For instance, TeV (non thermal) neutrinos produced in jetted SNe (Razzaque, Meszaros & Waxman'05)

Matter effects in sources

High energy neutrinos from a jet model of Supernovae
(Razzaque, Meszaros & Waxman'05) Mechanism is similar to the GRB case but slower.

These SNe are located in Starburst galaxies (@few Mpc, 1 Mpc =3.08 x 10^{22}m)
where the SN rate is higher than in the Milkyway or in the Magellanic clouds (0.1 SN/yr)
The combined SN rate from all galaxies within 20 Mpc is more than 1/yr.

Since they are transient nearby sources, the atmospheric neutrino background is negligible, using temporal and positional coincidences with optical detections



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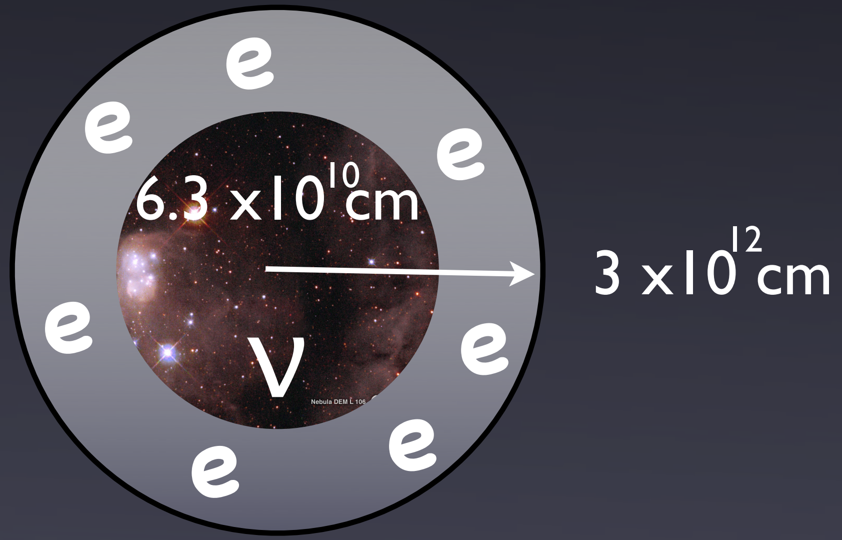
$$N_e(r) = 2.5 \cdot 10^{18} \left(\frac{3 \cdot 10^{12}}{r} - 1 \right)^3 \ \mathrm{cm}^{-3}$$



$$\sqrt{2} G_F N_e(r) = \frac{\Delta m^2_{13}}{2E} \cos 2\theta_{13}$$

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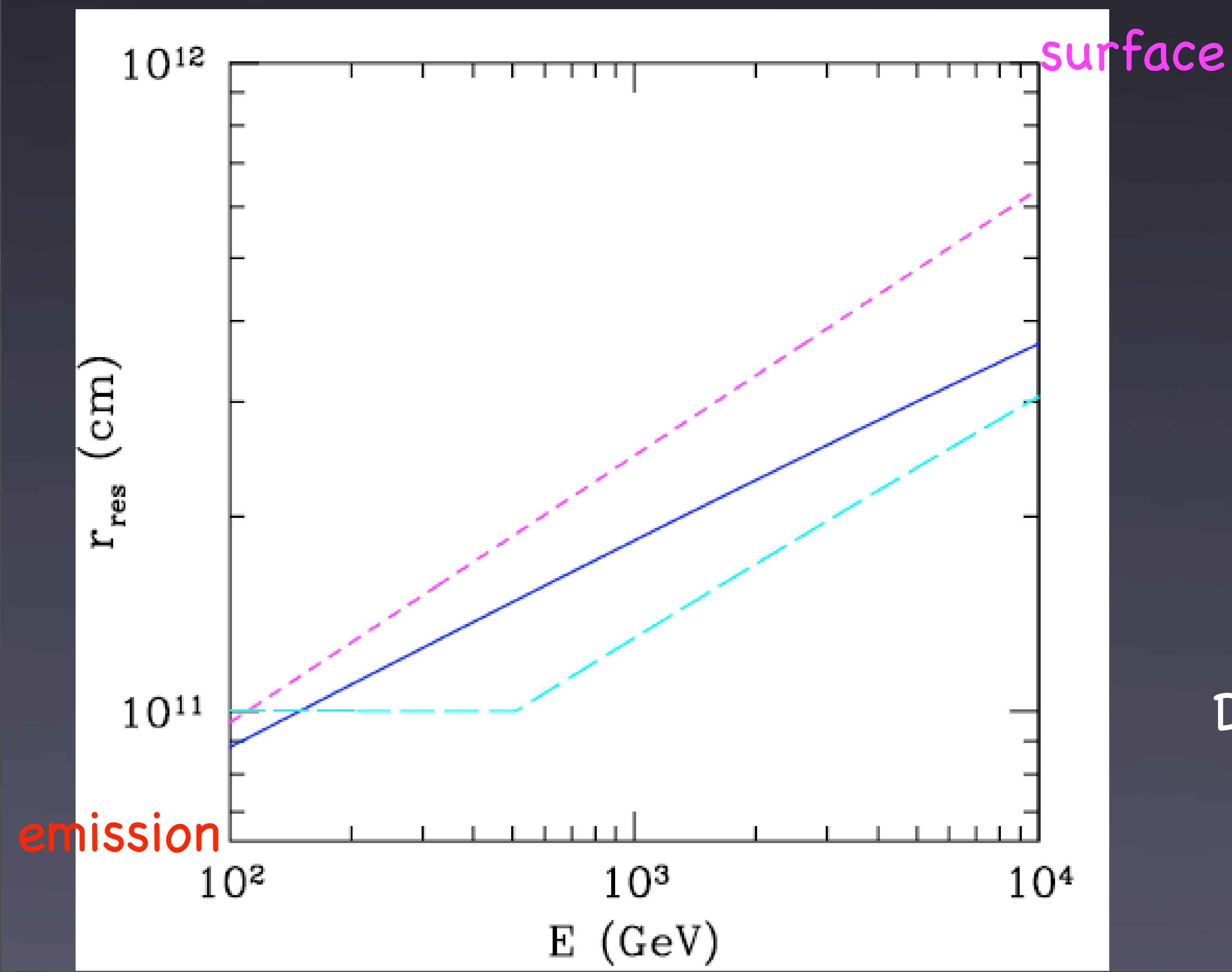

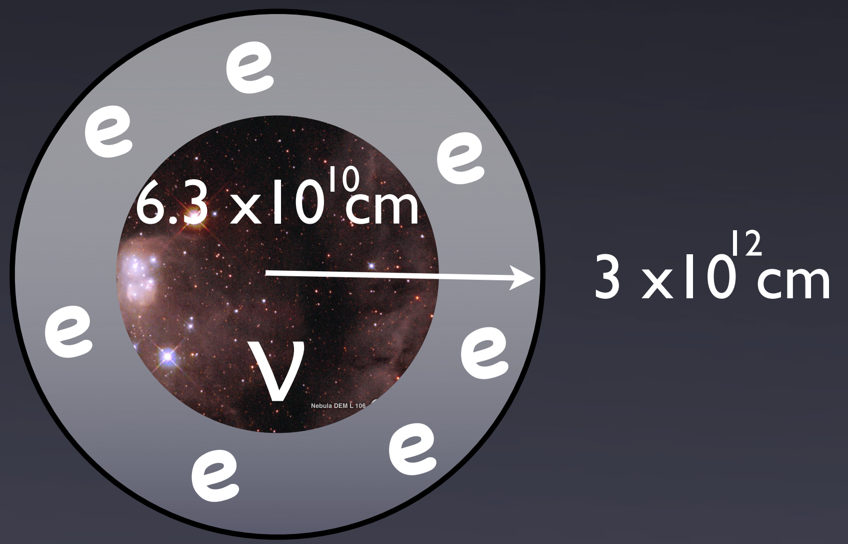

Distance from the center of the source
at which the resonance is met,
as a function of the neutrino energy

Matter effects in sources

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Standard expectation at the source:

$$\nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$$

could be modified by 20-50%!

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Propagation in vacuum, from the source to the Earth: in the case of exact $\nu_\mu \leftrightarrow \nu_\tau$ symmetry, the **standard expectation at the Earth**

$$\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$$

is also modified!

Propagation from the Source to the Earth

The STANDARD neutrino flavor ratios at the source are:

$$\nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$$

The distance between the source and Earth is huge, much larger than the oscillation length
Neutrino oscillations occur many many times: the information in the phases is lost, oscillations are averaged.
Neutrino weak eigenstates: incoherent mixture of the neutrino mass eigenstates.

In the case of exact $\nu_\mu \leftrightarrow \nu_\tau$ symmetry,

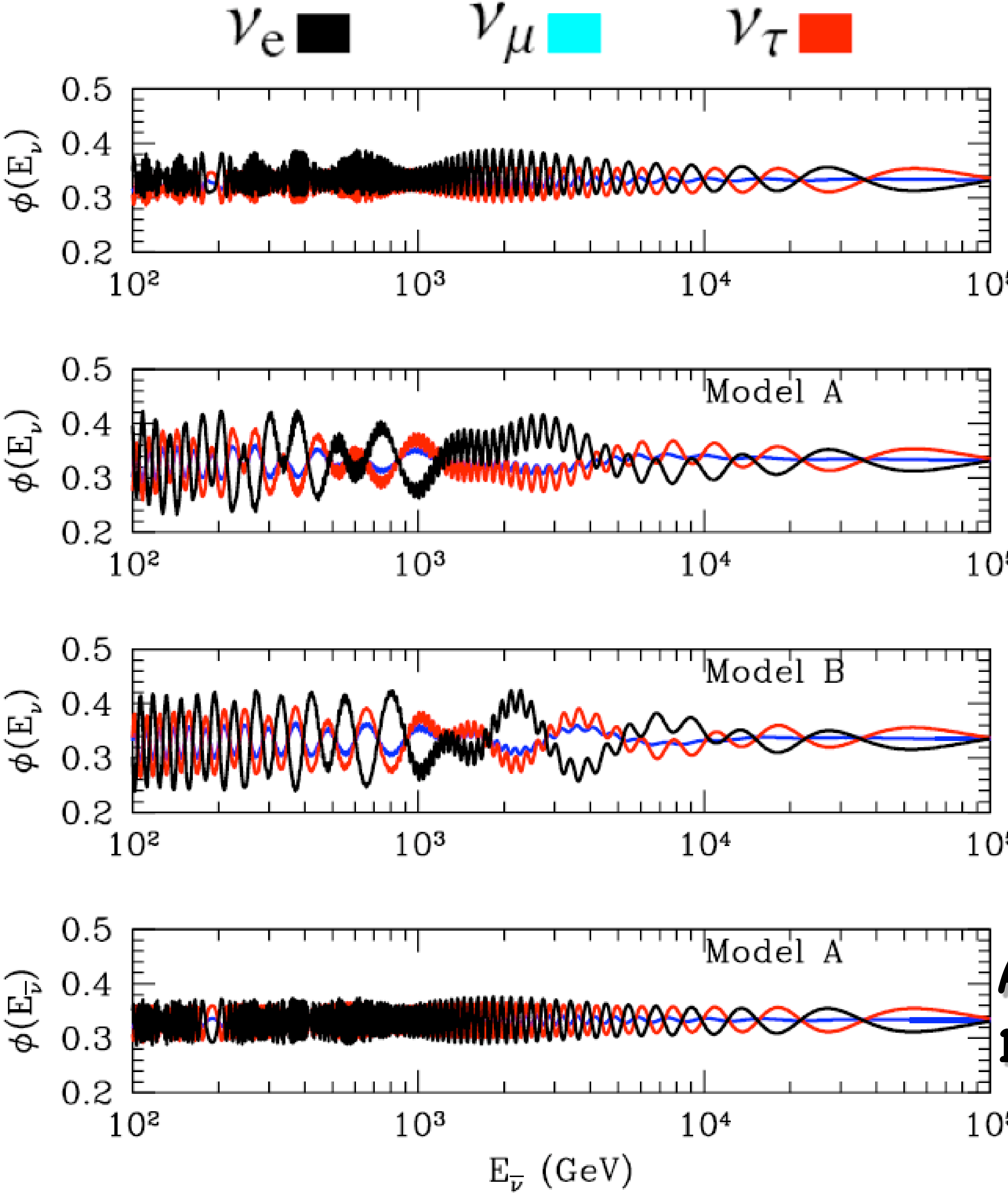
$$\theta_{23} = 45^\circ \qquad |U_{e3}|^2 << 1$$

the STANDARD expectation at the Earth is:

$$\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$$

vacuum:

1/3:1/3:1/3



Antineutrino

1/3:1/3:1/3

Matter effects in sources

The observable we have chosen: shower-to-muon-track ratio at Icecube.

$$R = \frac{N_{shower}}{N_{track}} = \frac{N_{\nu_e}+N_{\bar{\nu}_e}+N_{\nu_\tau}+N_{\bar{\nu}_\tau}}{N_{\nu_\mu}+N_{\bar{\nu}_\mu}}$$

In the vacuum scenario,

R=2 ENERGY INDEPENDENT

Energy binning of the signal assuming a very conservative energy resolution:

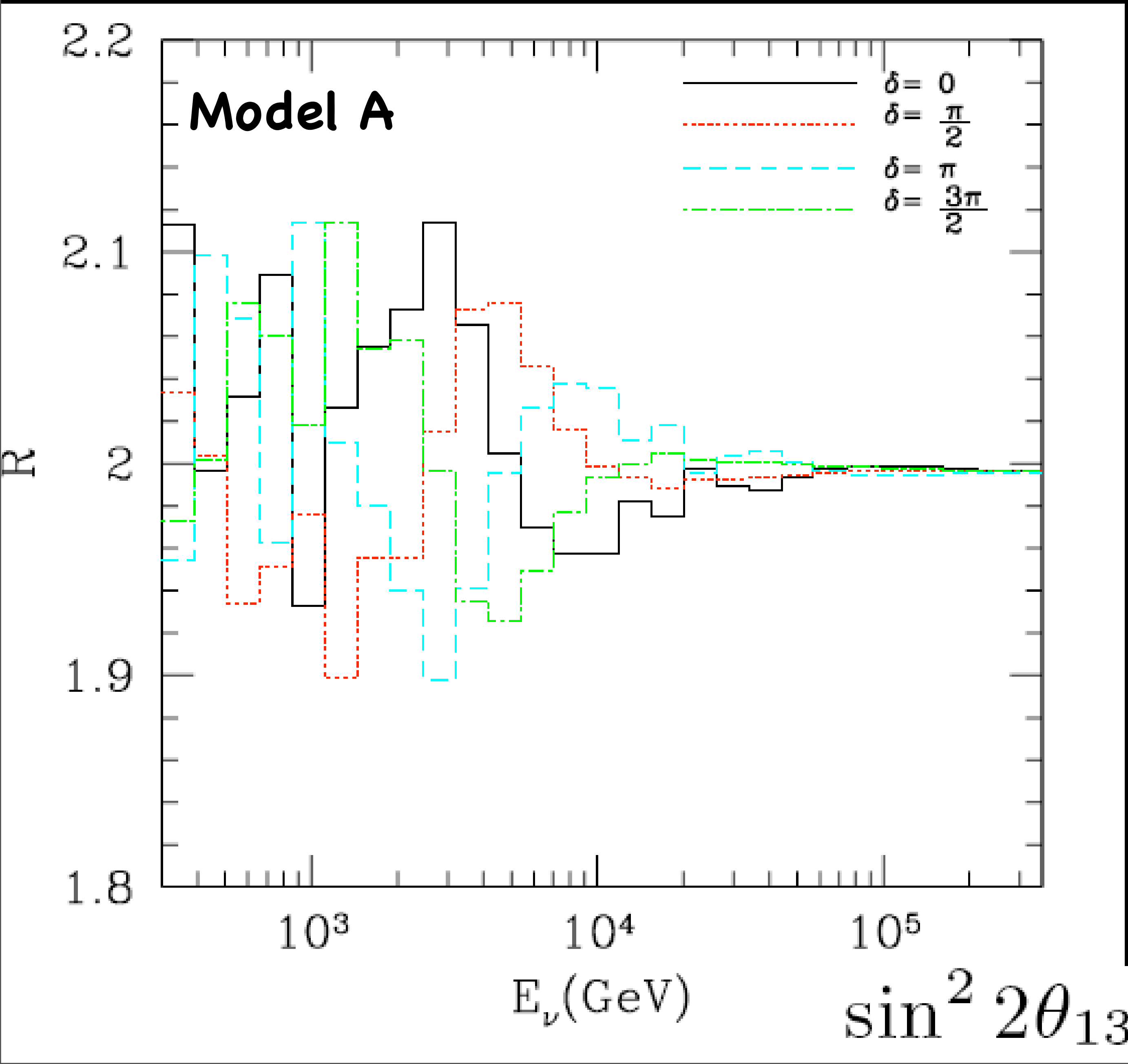
$$\Delta E_\nu = 0.3 E_\nu$$

(i.e dlog E = 30%) at Icecube. We are LUCKY, since the effect is located at an energy range in which Icecube energy resolution capabilities are OPTIMAL!

Matter effects in sources

In the vacuum scenario, for optically thin sources:

R=2 ENERGY INDEPENDENT



$\sin^2 2\theta_{13} = 0.15$

Normal hierarchy:
Only neutrinos encounter the resonance density while traversing the source.

If a deviation from R=2 is measured at E < 4 TeV it could be possible to infer a non zero value of θ_{13}

Matter effects in sources

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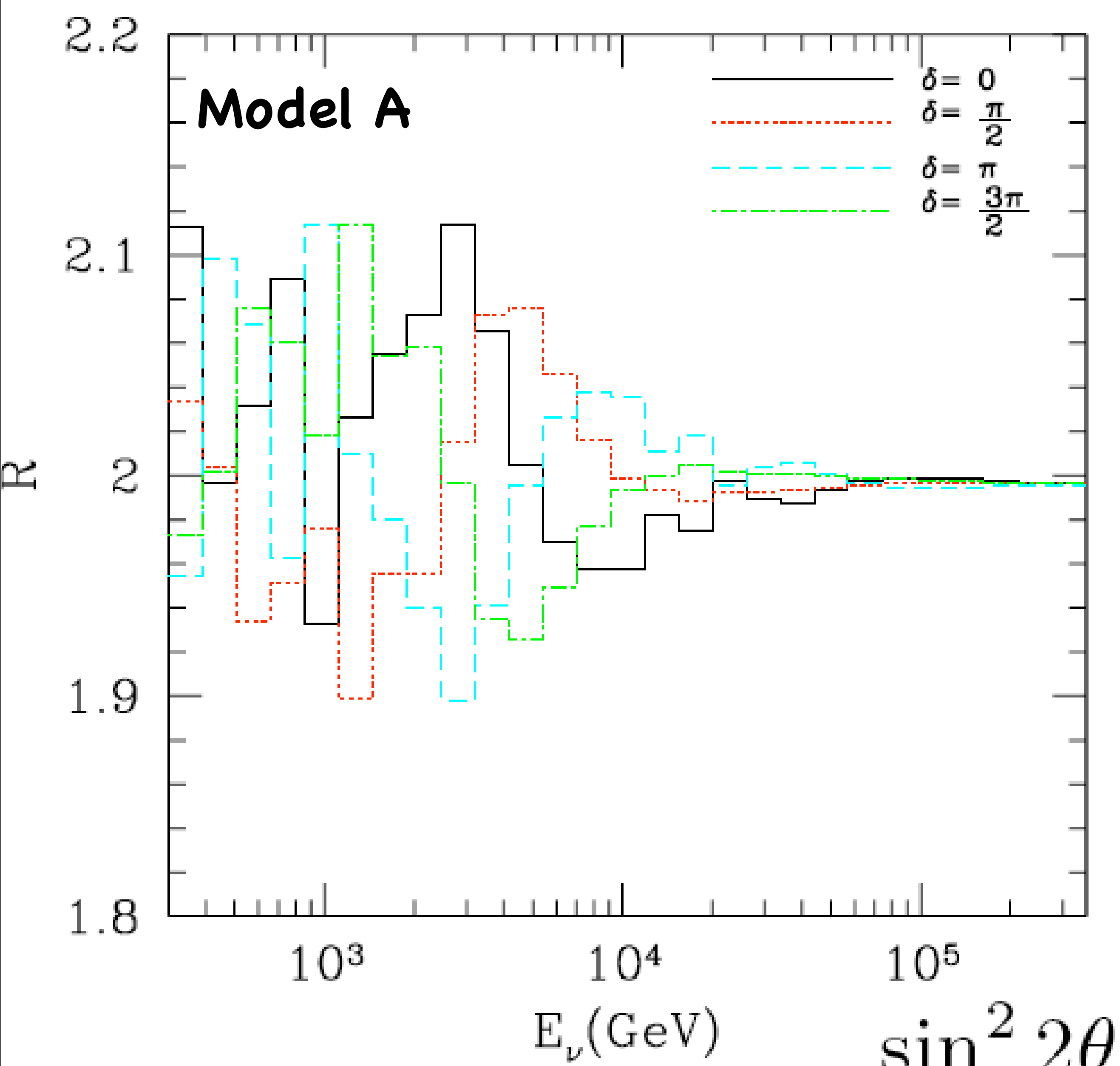

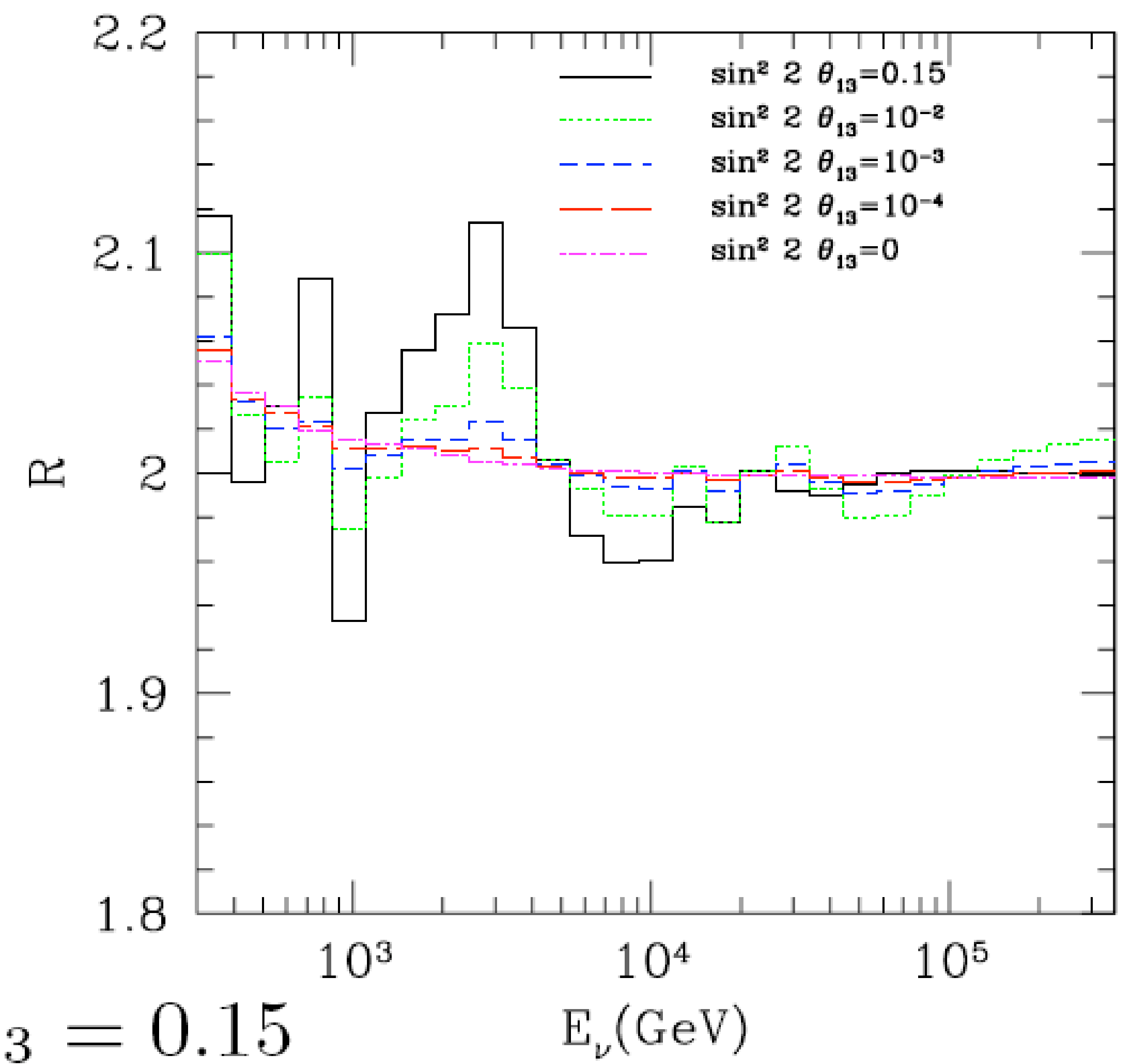

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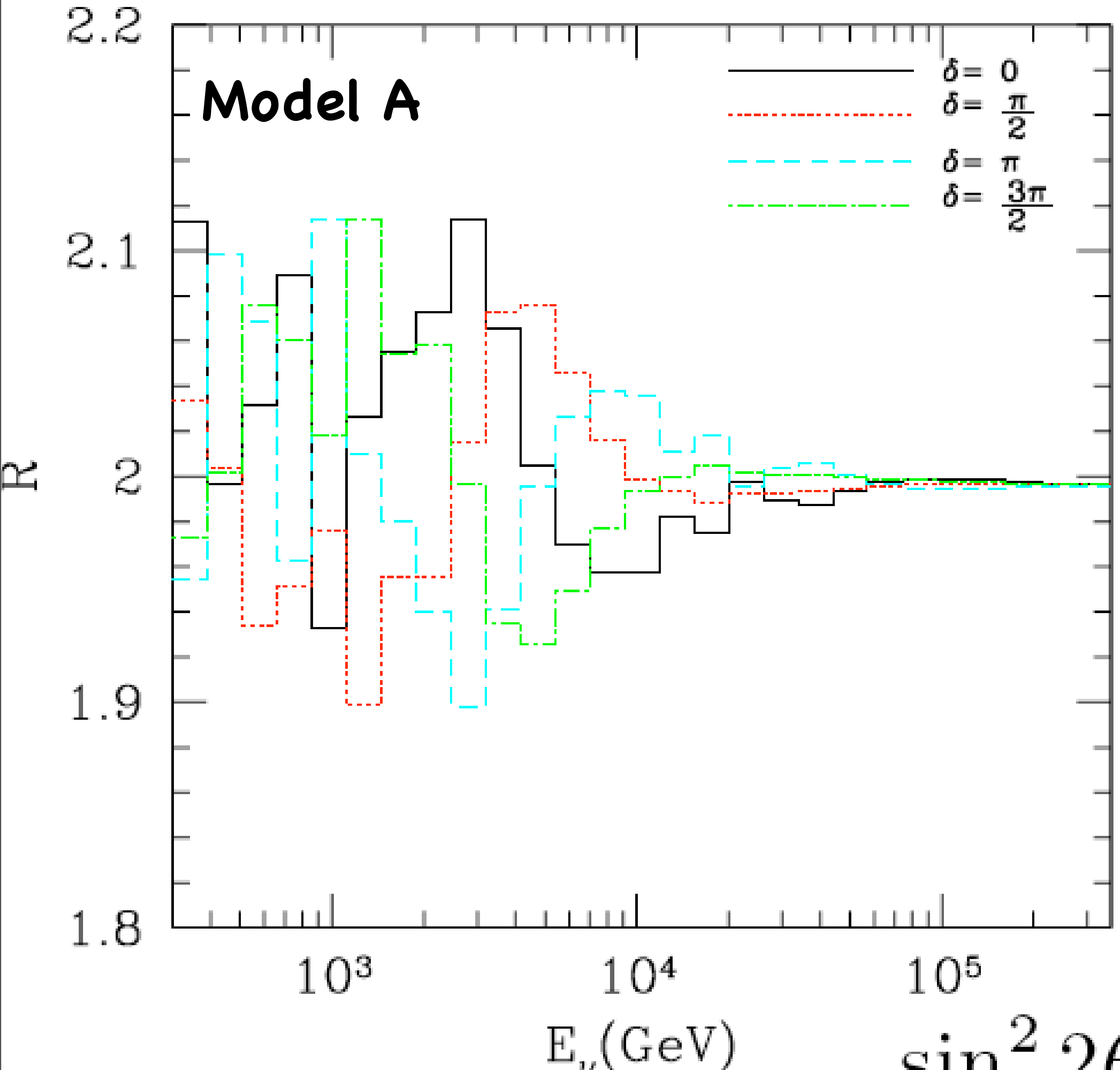

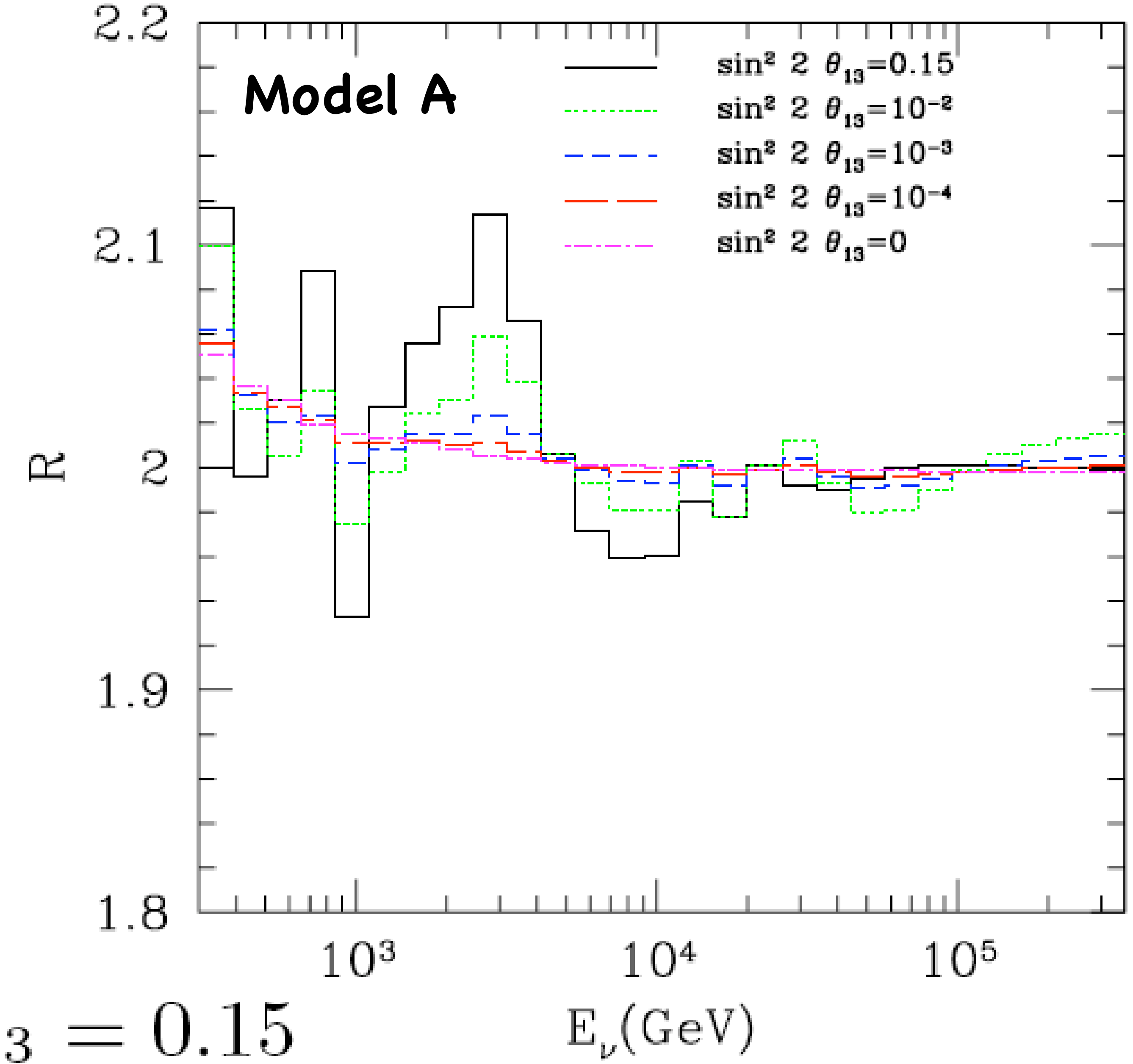

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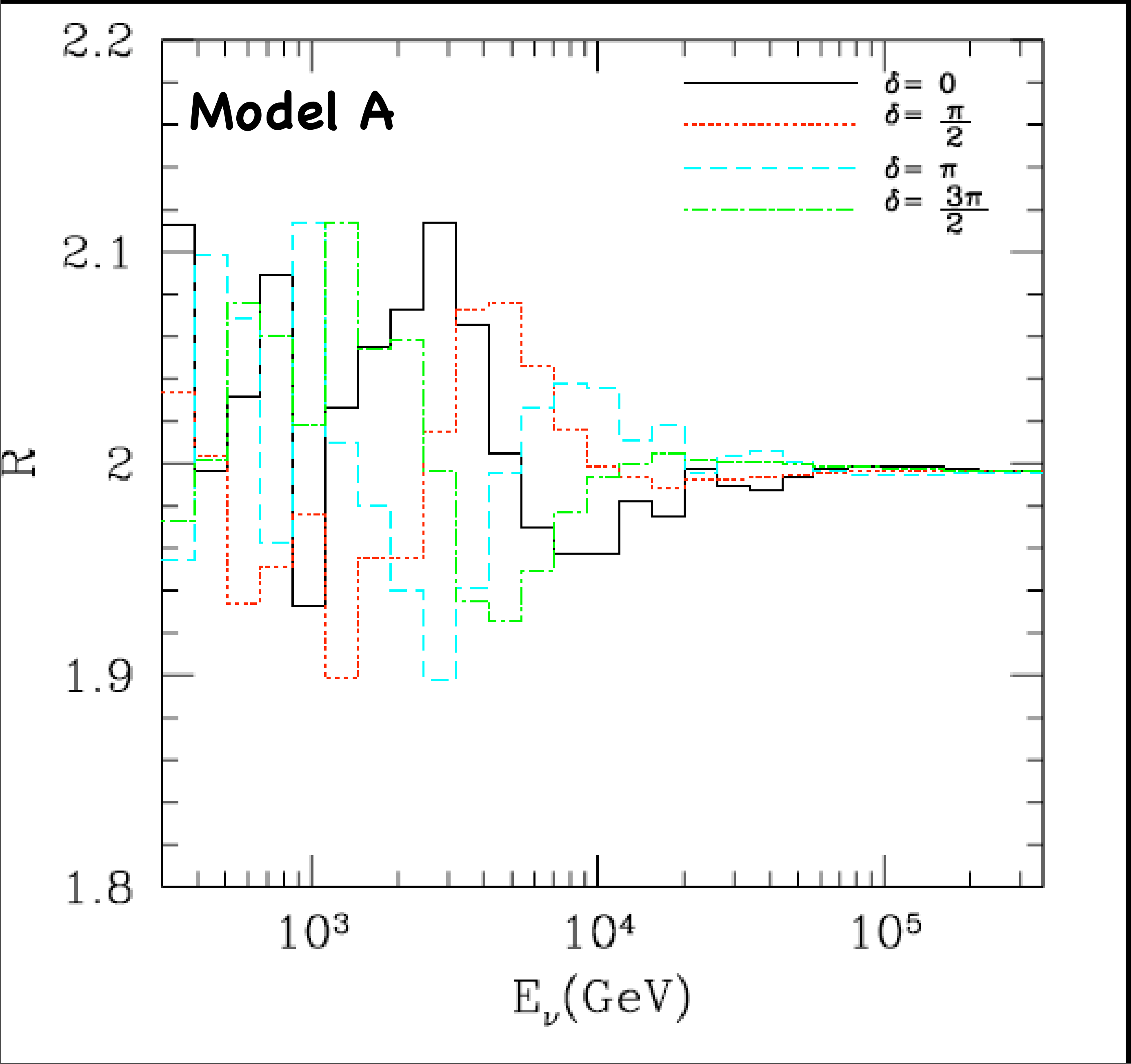

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Extracting the CP Violating phase:
HIGHLY CHALLENGING!
A precise knowledge of the matter density profile absolutely required!

Matter effects in sources

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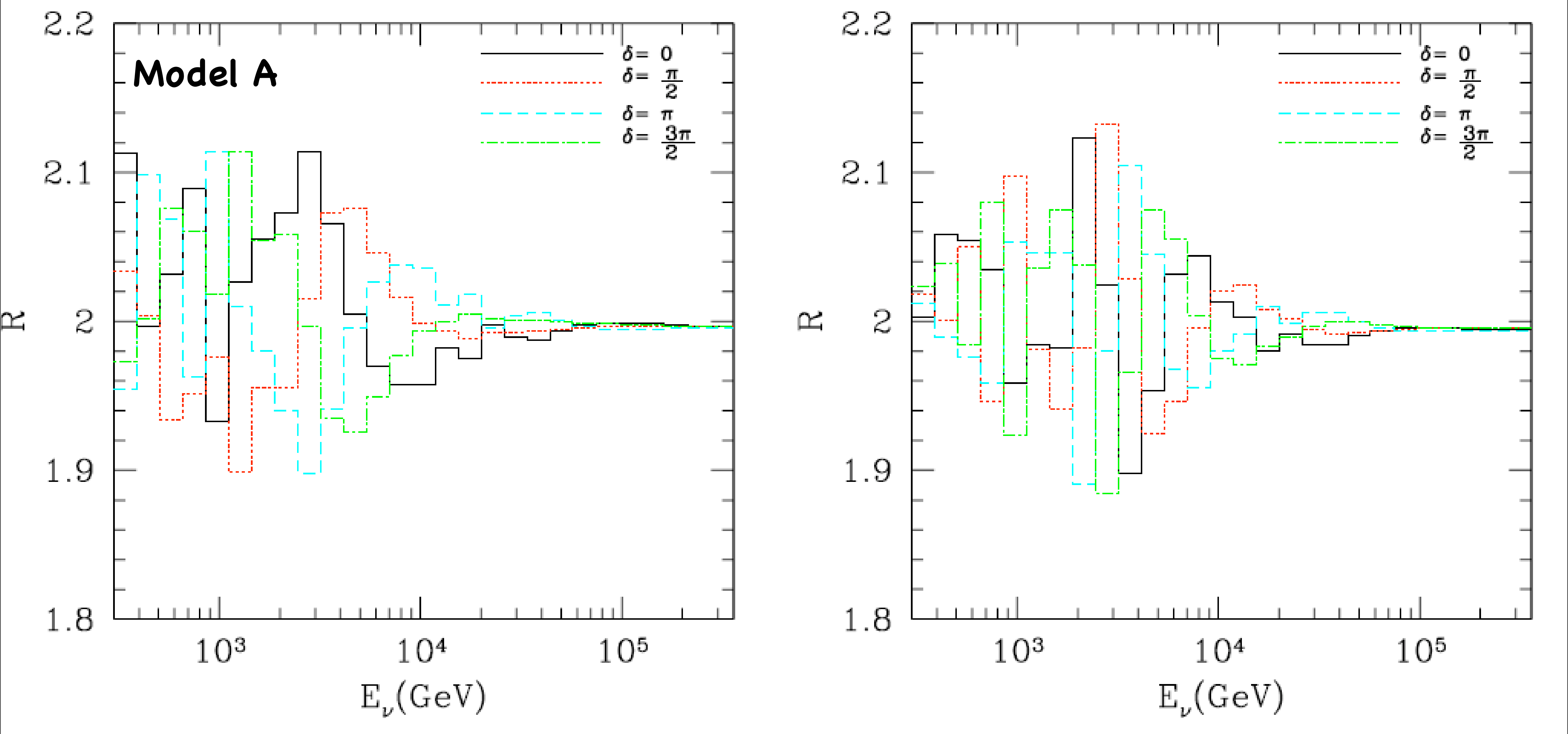

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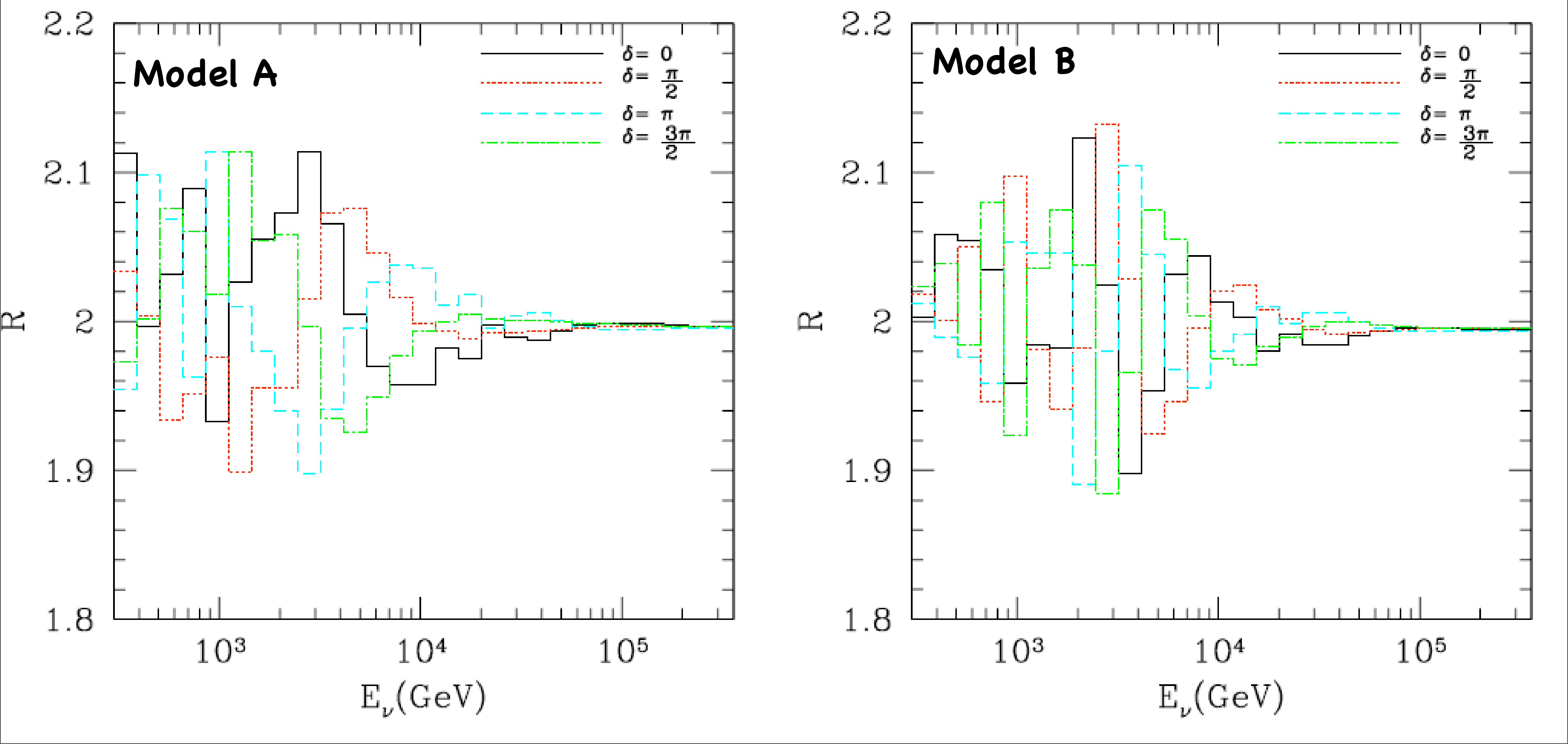
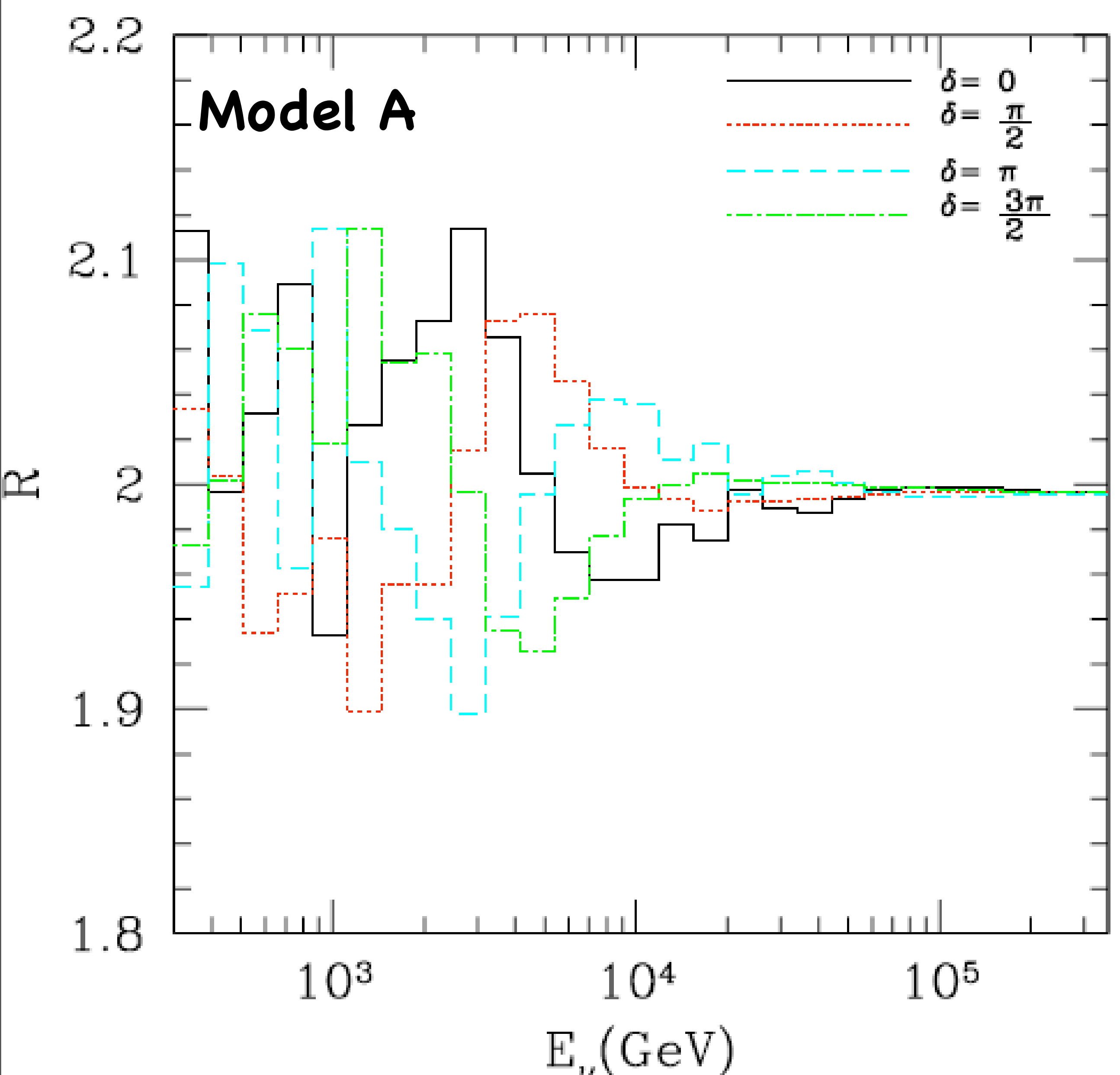


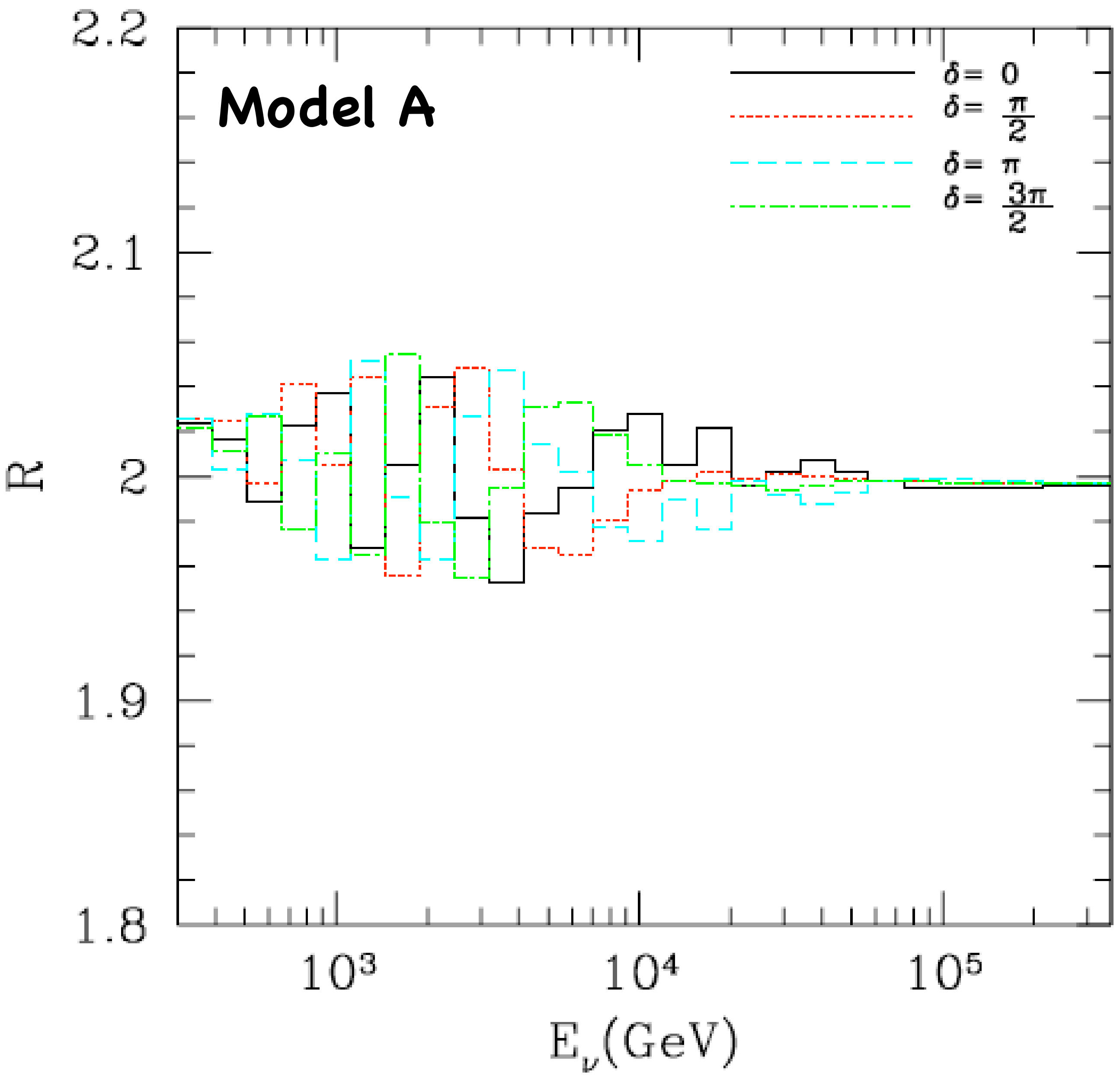
Matter effects in sources

Would it be possible to extract the neutrino mass ordering, i.e normal versus inverted?

NORMAL HIERARCHY



INVERTED HIERARCHY



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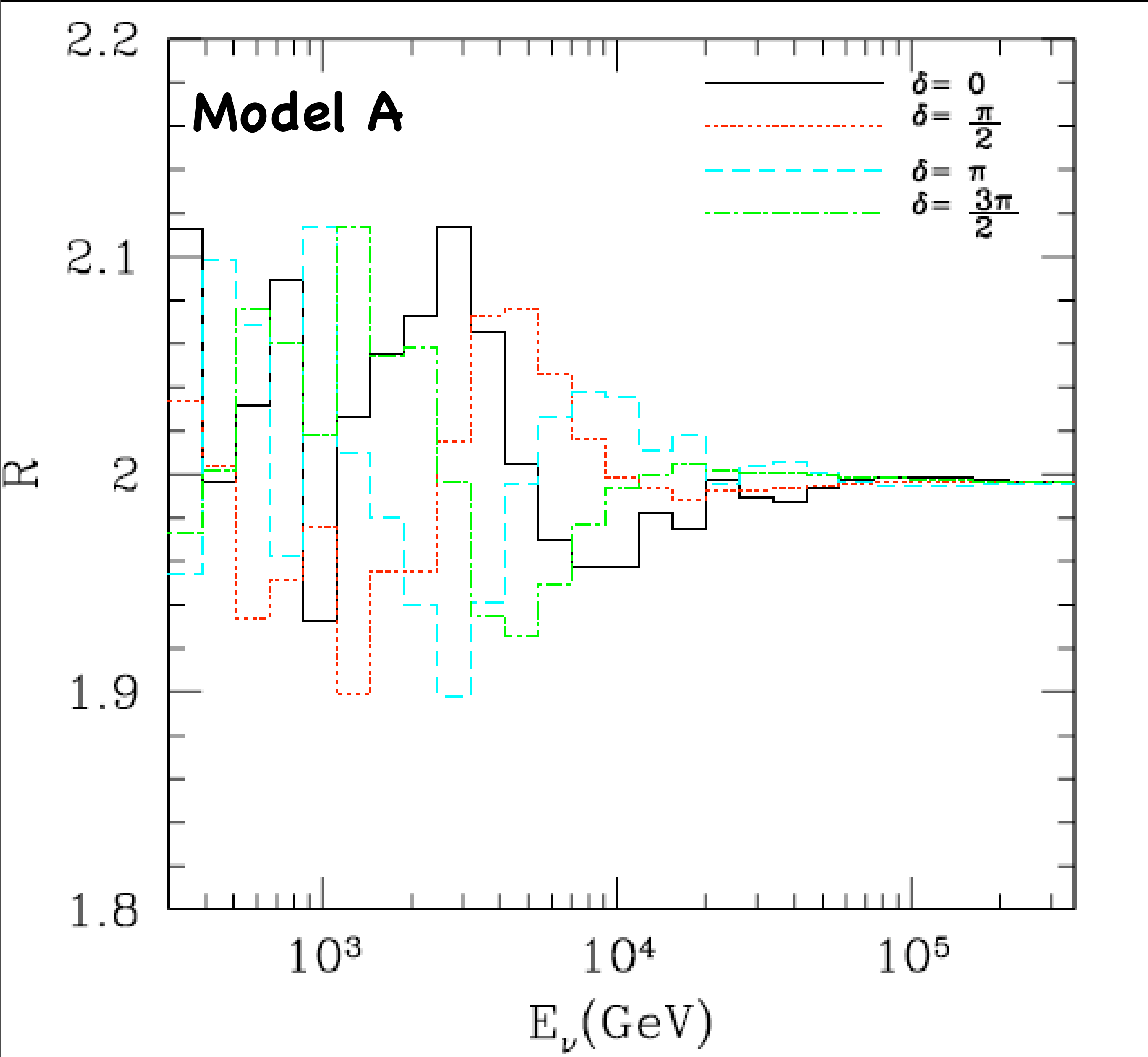
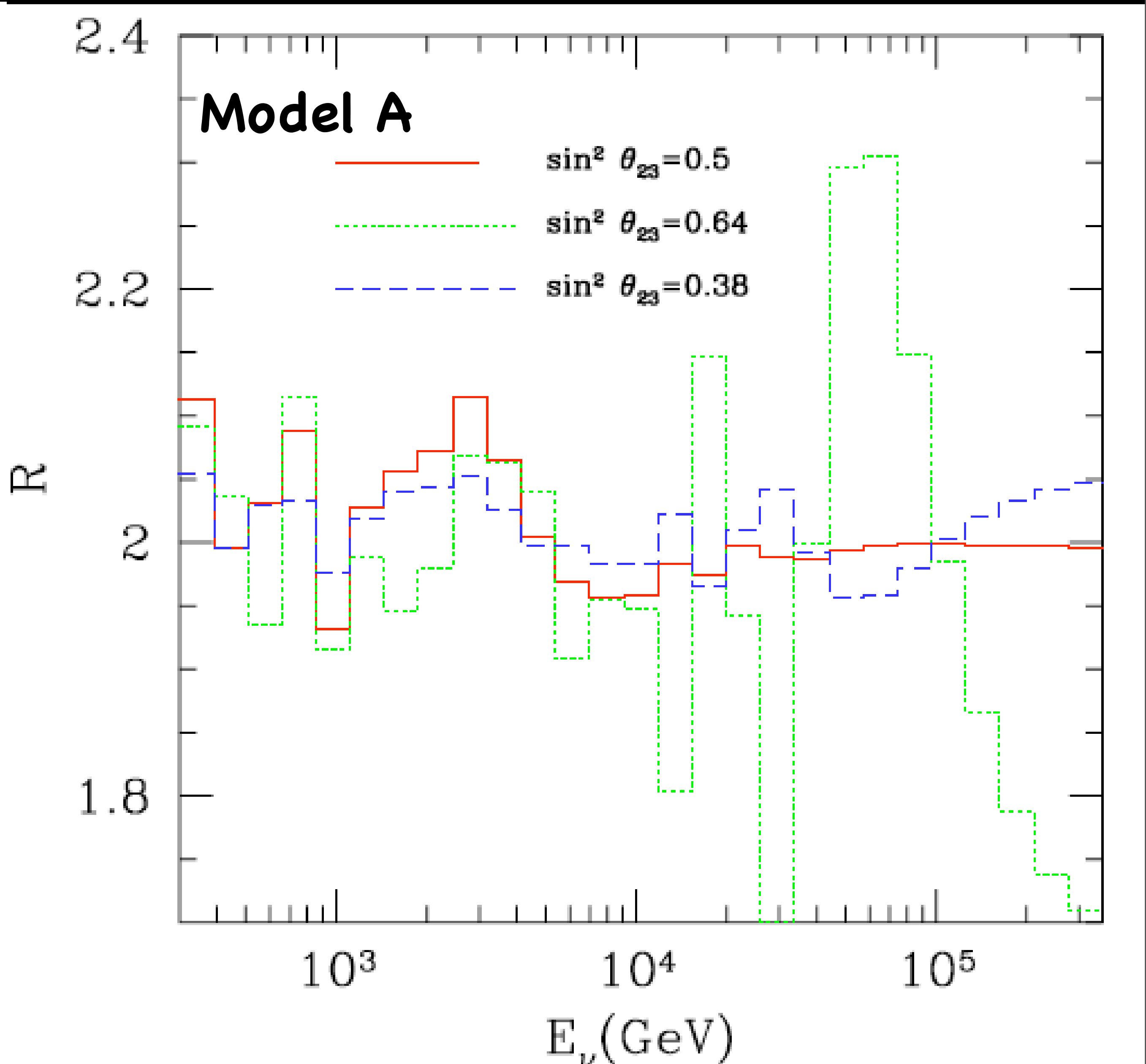
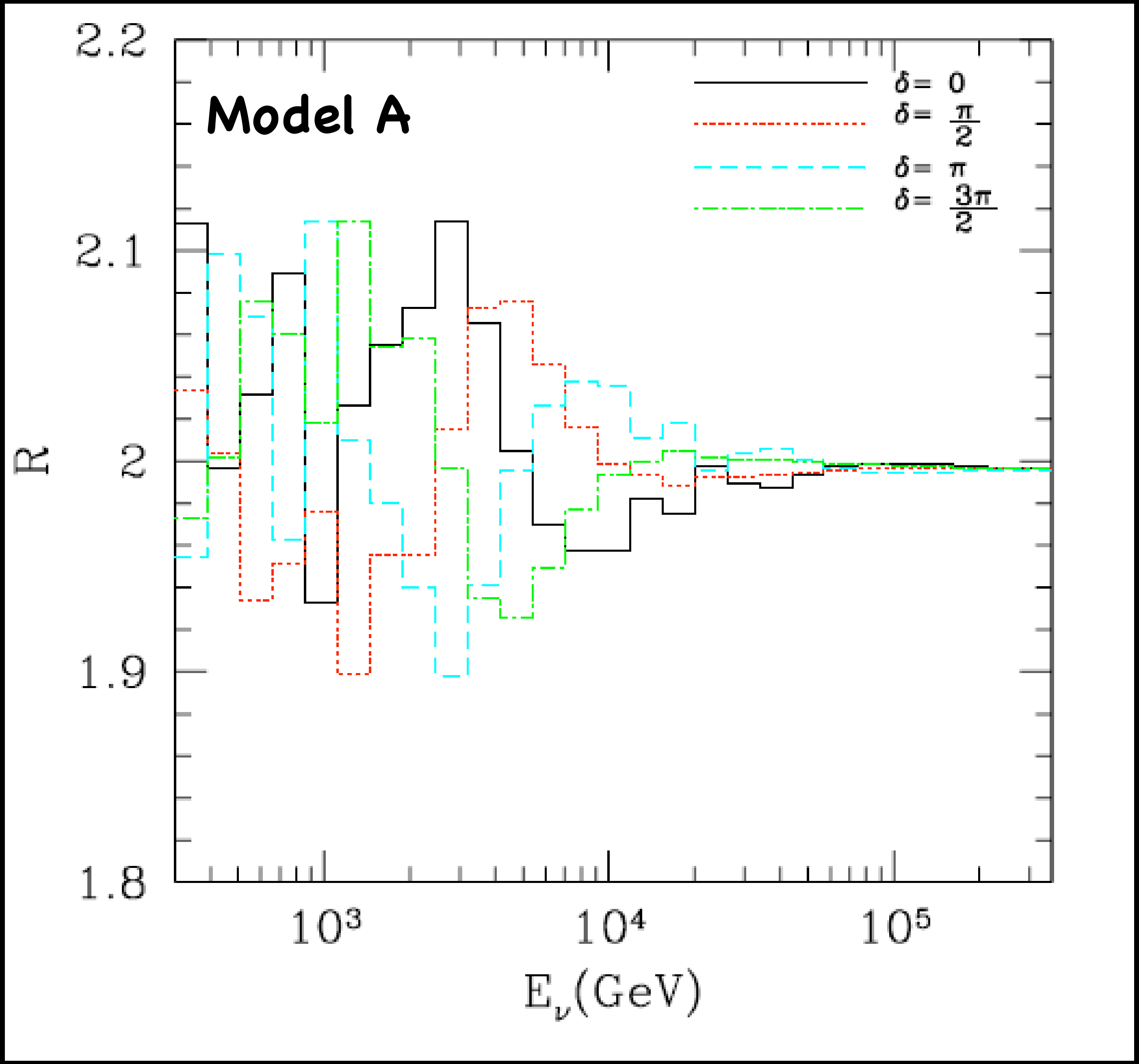


NORMAL HIERARCHY



Matter effects in sources

A separate measurement of the tau component would help enormously in extracting both the neutrino mass hierarchy and the atmospheric mixing angle!



Unfortunately:

Matter effects leave an imprint at TeV energies

Tau decay length:

$$l_\tau \approx 50 \text{ m} \times (E_\tau / 10^6 \text{ GeV})$$

Below PeV tau neutrino tagging is not possible. The two showers can not be separated (double bang signal is not present)

Matter effects in sources

(with Irina Mocioiu and Soeb Razzaque, PRD'06)

The number of events required to establish a 3 sigma effect would be 1000, requiring therefore a relatively nearby source, within a few Mpc.

It would be possible to investigate (unknown?) neutrino properties as CP Violation or the mass hierarchy, assuming that there would be a more precise knowlegde of the mixing angles.
If the neutrino sector is known precisely, the shower-to-muon track ratio could be used to infer the properties of the source (matter profile).

Matter effects would be the most natural explanation of an energy dependent deviation of R from its value in vacuum measured by upcoming neutrino telescopes!

Propagation in vacuum from the source to the Earth:

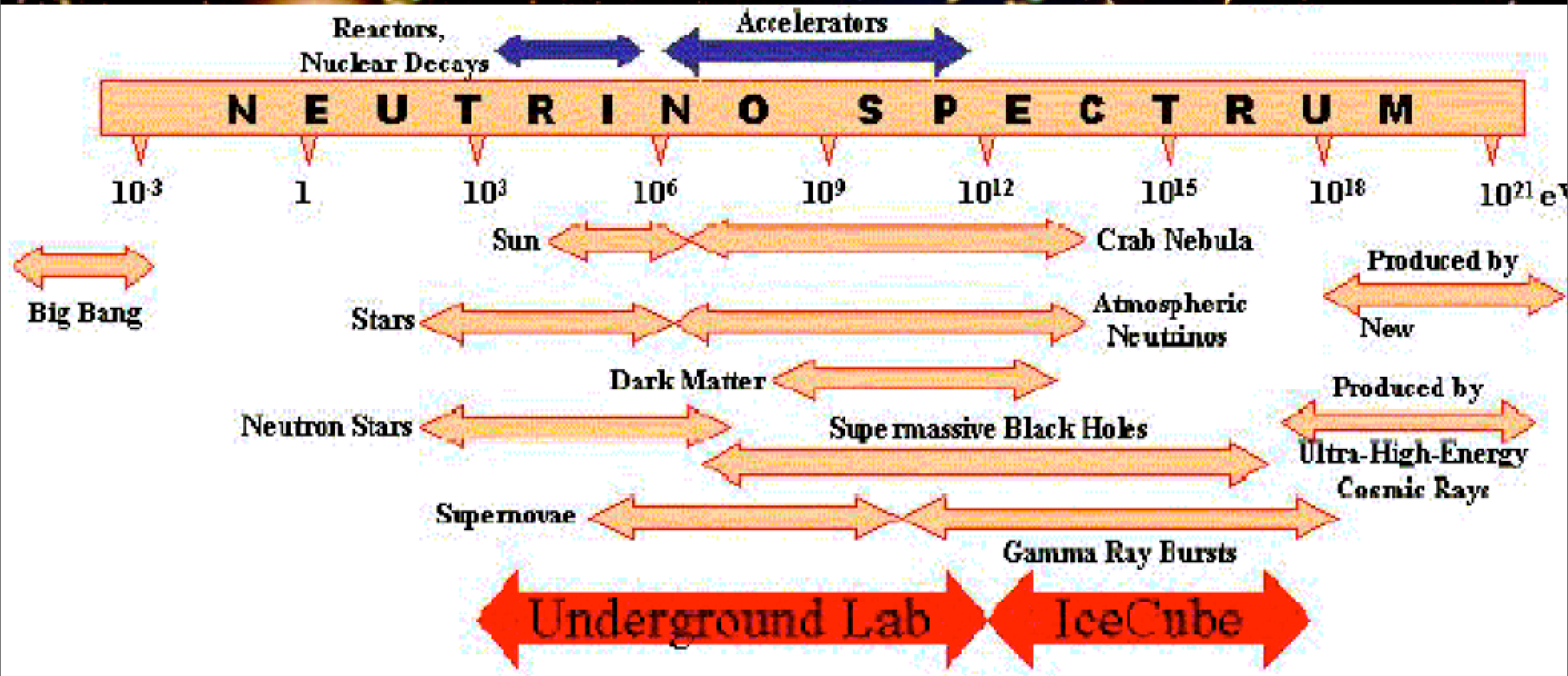
What is going on if we do not see 1:1:1?

Exotic scenarios:

- Neutrino Decay (Beacom, Bell, Hooper, Pakvasa & Weiler)
- CPT Violation (Barenboim & Quigg)
- Pseudo-Dirac mixing (Beacom, Bell, Hooper, Learned, Pakvasa & Weiler)
- 3+1, 2+2 models with sterile neutrinos (Dutta, Reno & Sarcevic)
- Magnetic moment transitions (Enqvist, Keranen & Maalampi)
- Mass varying neutrinos (Fardon, Nelson & Weiner, Hung & Pas)
- Additional interactions (Anchodorqui, Goldberg, Gonzalez-Garcia, Halzen, Hooper, Sarkar & Weiler ; Illana, Massip & Meloni)

Flavor tagging is essential!

Multi-messenger neutrino astronomy.



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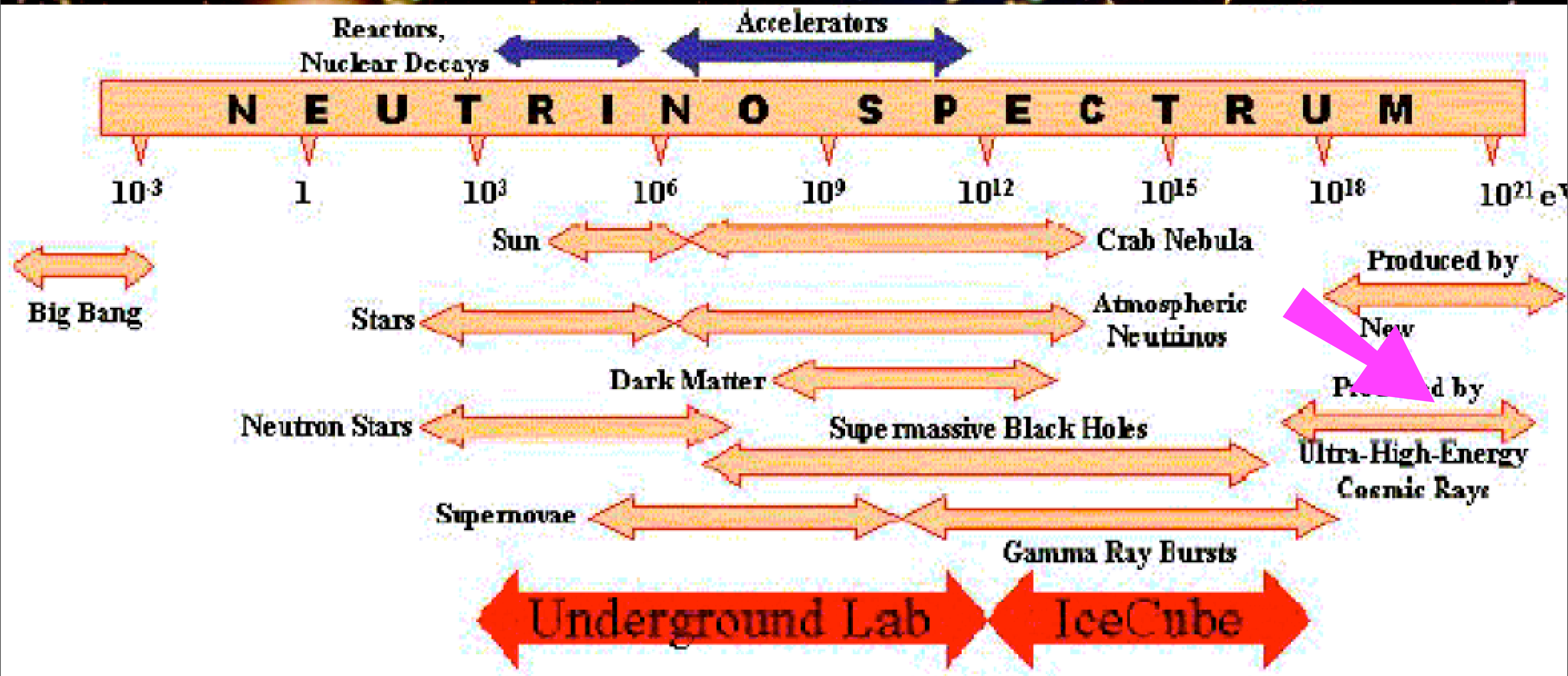

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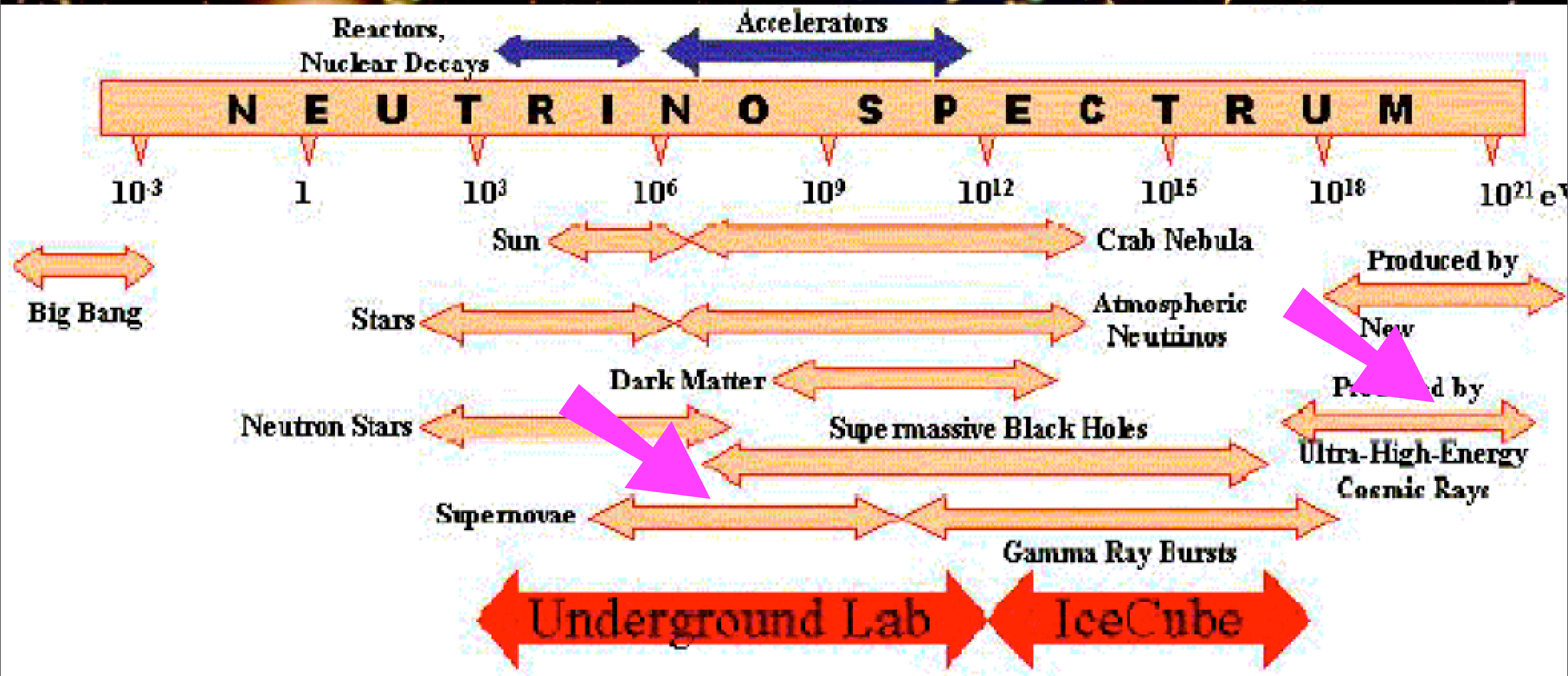
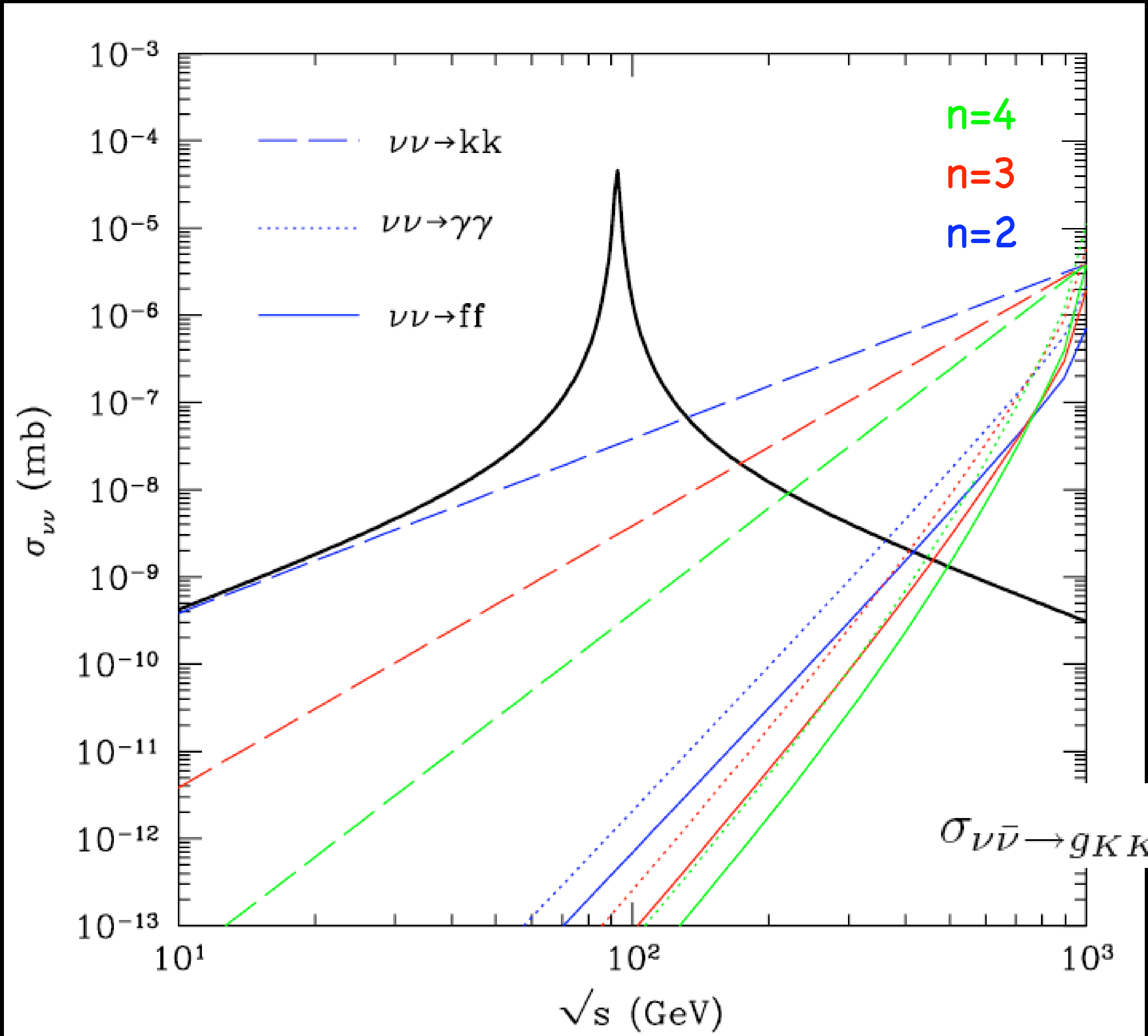


UHE neutrinos as probes of large extra dimensions

(with J. Lykken and S. Razzaque, hep-ph/0705.2029)

Presence of strongly interacting processes can modify the neutrino-antineutrino annihilation cross section at high s-values (Han, Lykken & Zhang, PRD'99).

New physics constrained from SN 1987A observations(< 30, 4 and 1 TeV for n=2,3 and 4ED)



$$\sigma_{\nu\bar{\nu}\rightarrow g_{KK}} = (\pi^2/s)(s/M_S^2)^{n/2+1}$$

UHE neutrinos as probes of extra dimensions

The Beam: A "guaranteed" source of UHE neutrino fluxes, originated by UHECR interactions with the CMB photons dominantly via Δ^+ processes:
GZK or cosmogenic neutrinos.

The Target: The Diffuse cosmic supernovae neutrinos, sum of neutrinos from all past supernovae.

In principle, CMB cosmic neutrinos are also a possible target, but their temperature (1.95 K) makes them to be an almost negligible "secondary target", when compared to the
10 MeV SN relic neutrinos.

The neutrino-Nucleon cross section is enhanced as well, but
(a) it occurs at higher energies, and
(b) the UHE neutrino flux will be depleted in-route-to-the Earth (DSN neutrino annihilation).

(I) The diffuse SN relic neutrino background

Flux of neutrinos from all SN which have occurred along the universe's history.

Current experimental limits:

Experiment,species	channel	energy interval	upper limit ($cm^{-2}s^{-1}$)
KamLAND, $\bar{\nu}_e$ [7]	$\bar{\nu}_e + p \rightarrow n + e^+$	$8.3 < E/MeV < 14.8$	3.7×10^2 (90% C.L.)
SK, $\bar{\nu}_e$ [3]	$\bar{\nu}_e + p \rightarrow n + e^+$	$E/MeV > 19.3$	1.2 (90% C.L.)
SK/indirect, ν_e [6]		$E/MeV > 19.3$	5.5 ($\sim$ 98% C.L.)
SK, ν_e [8]	$\nu_e + ^{16}O \rightarrow ^{16} F + e^-$	$E/MeV > 33$	61-220 (90% C.L.)
SNO, ν_e [9]	$\nu_e + ^2_1H \rightarrow p + p + e^-$	$22.9 < E/MeV < 36.9$	70
LSD, $\nu_\mu + \nu_\tau$ [10]	$\nu_{\mu,\tau} + ^{12} C \rightarrow ^{12} C + \nu_{\mu,\tau}$	$20 < E/MeV < 100$	$3 \cdot 10^7$ (90% C.L.)
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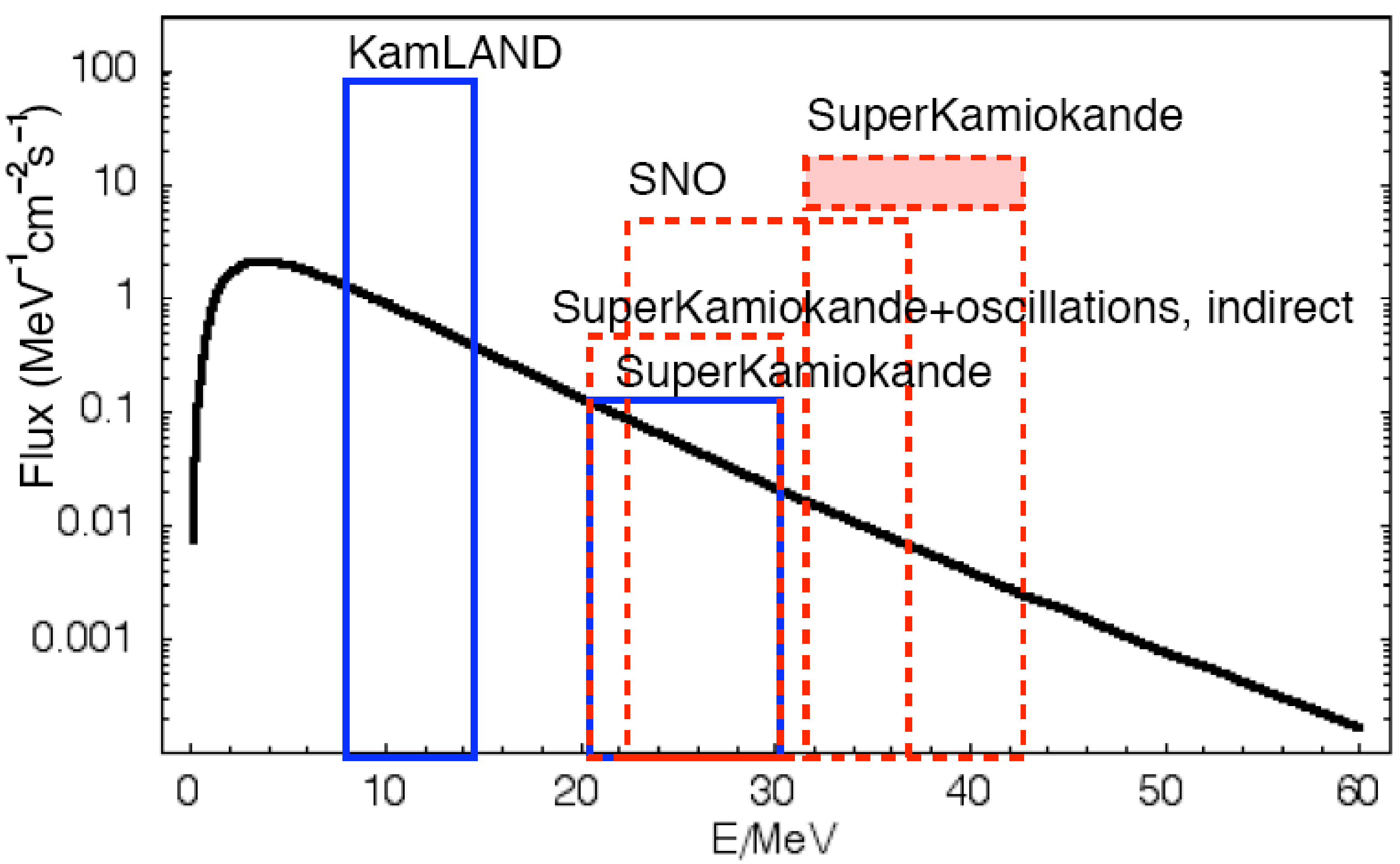
C. Lunardini, Neutrino'06



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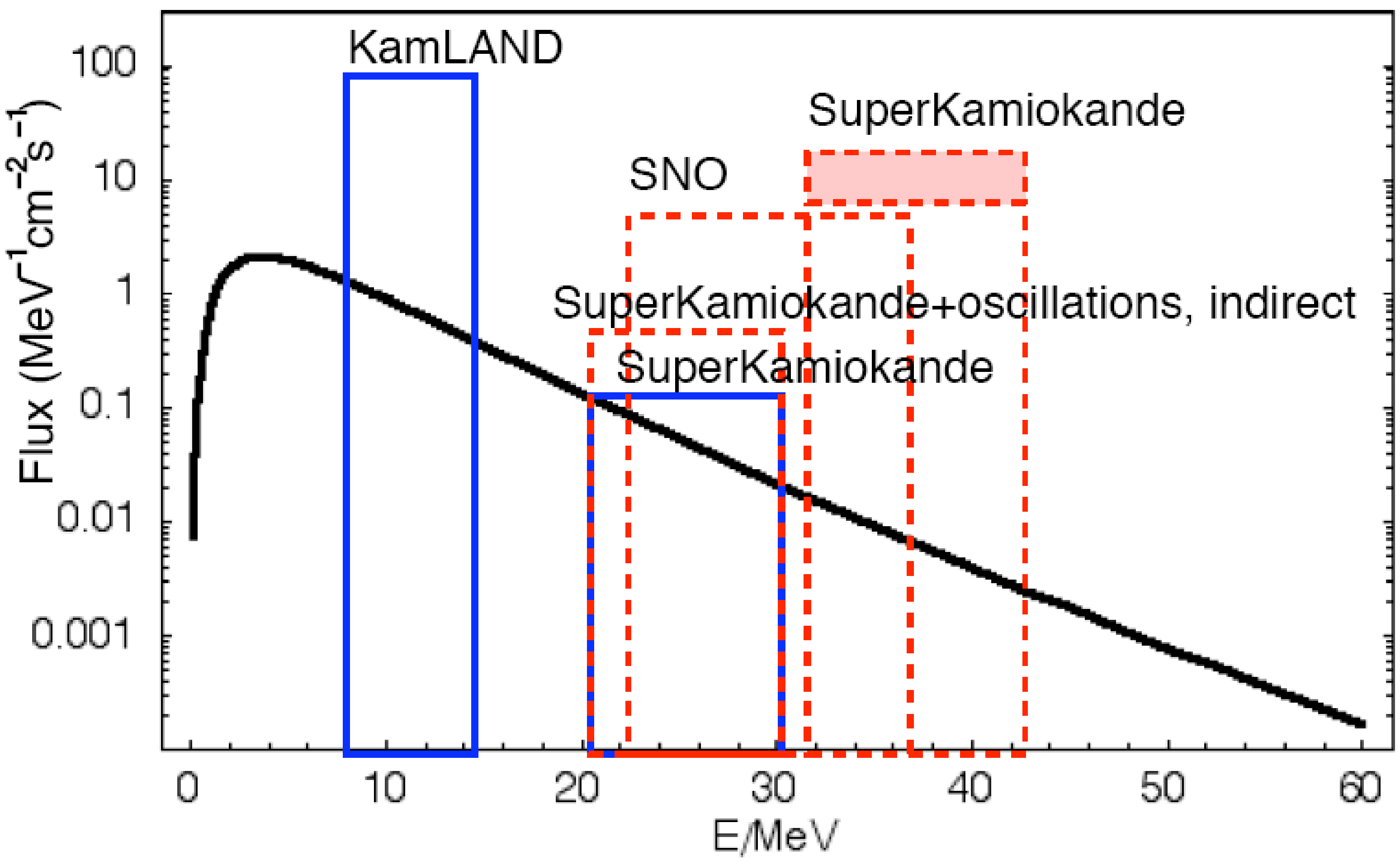


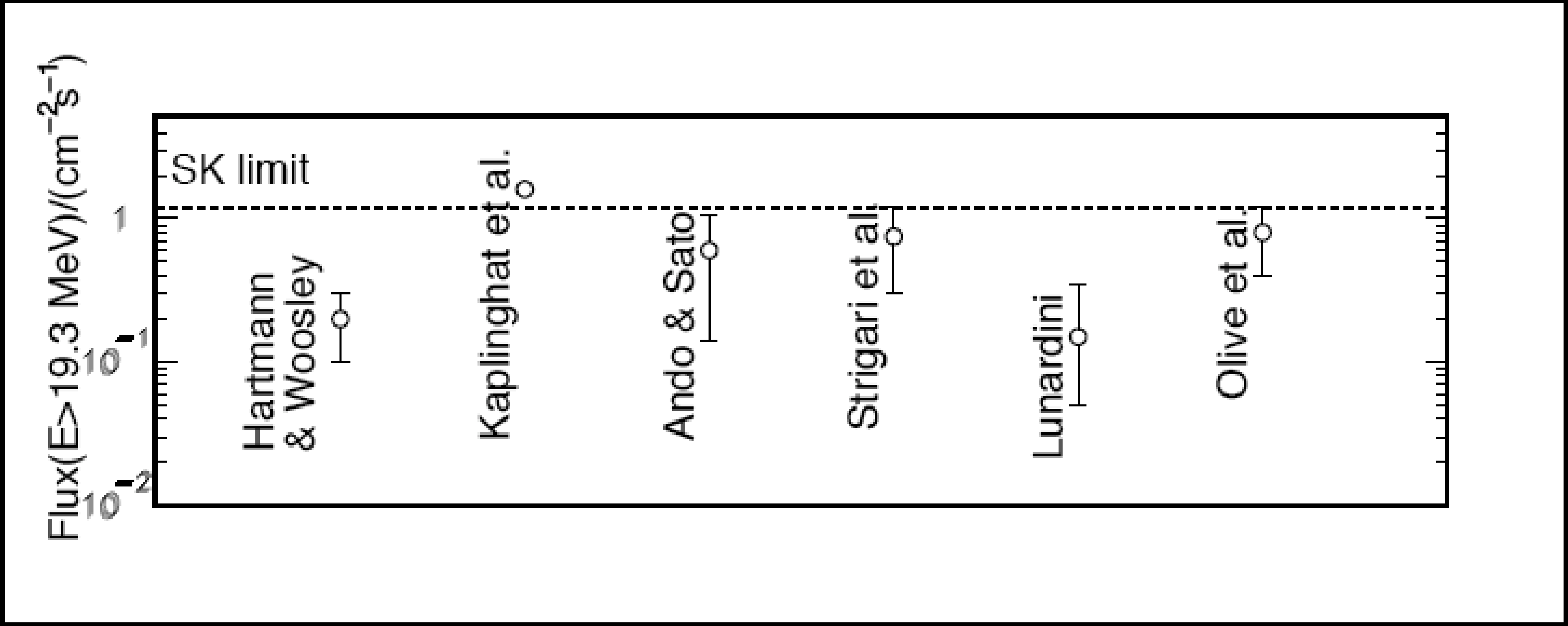
(I) The diffuse SN relic neutrino background

Formally:

$$\Phi(E) = \frac{c}{H_0} \int_0^{z_{max}} R_{SN}(z) \sum_{w=e,\mu,\tau} \frac{dN_w(E')}{dE'} P_{we}(E,z) \frac{dz}{\sqrt{\Omega_m(1+z)^3 + \Omega_\Lambda}}$$

Different theoretical predictions due to the different assumptions on SFRs and the numerical simulations of the neutrino spectra

C. Lunardini, Neutrino'06



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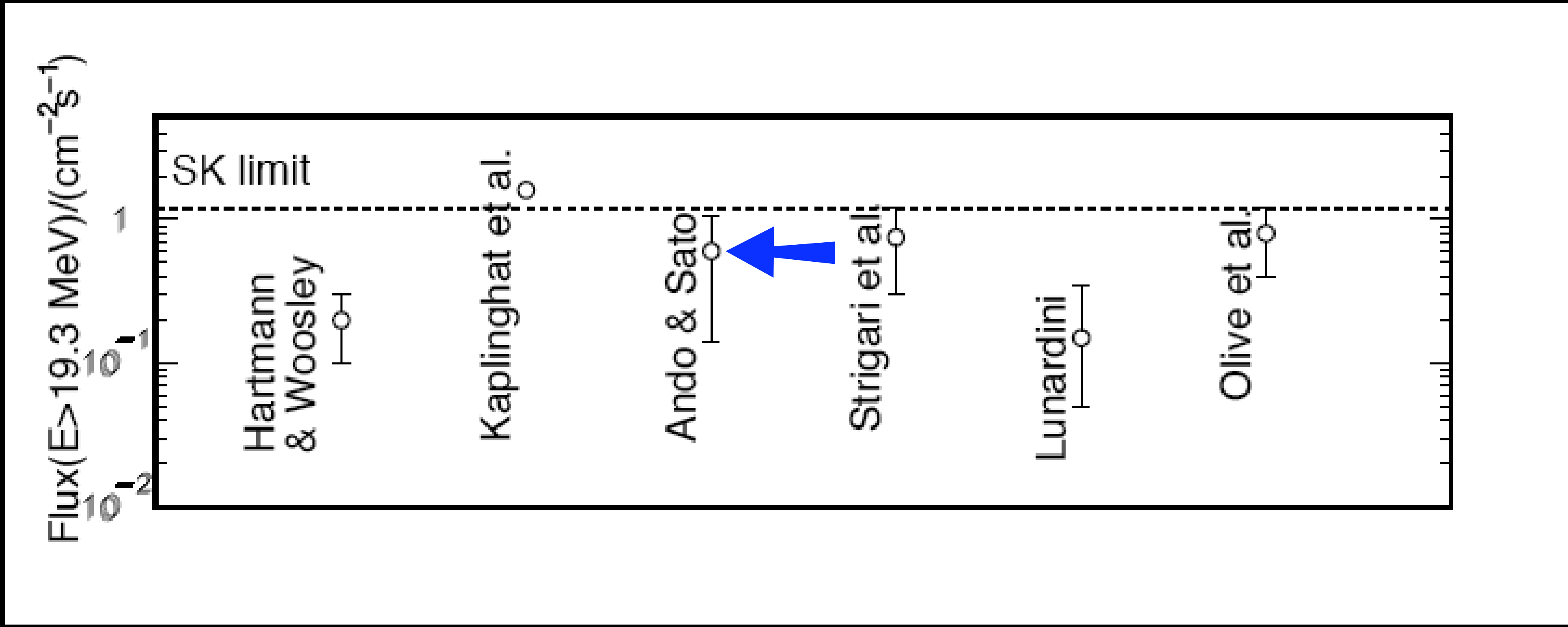

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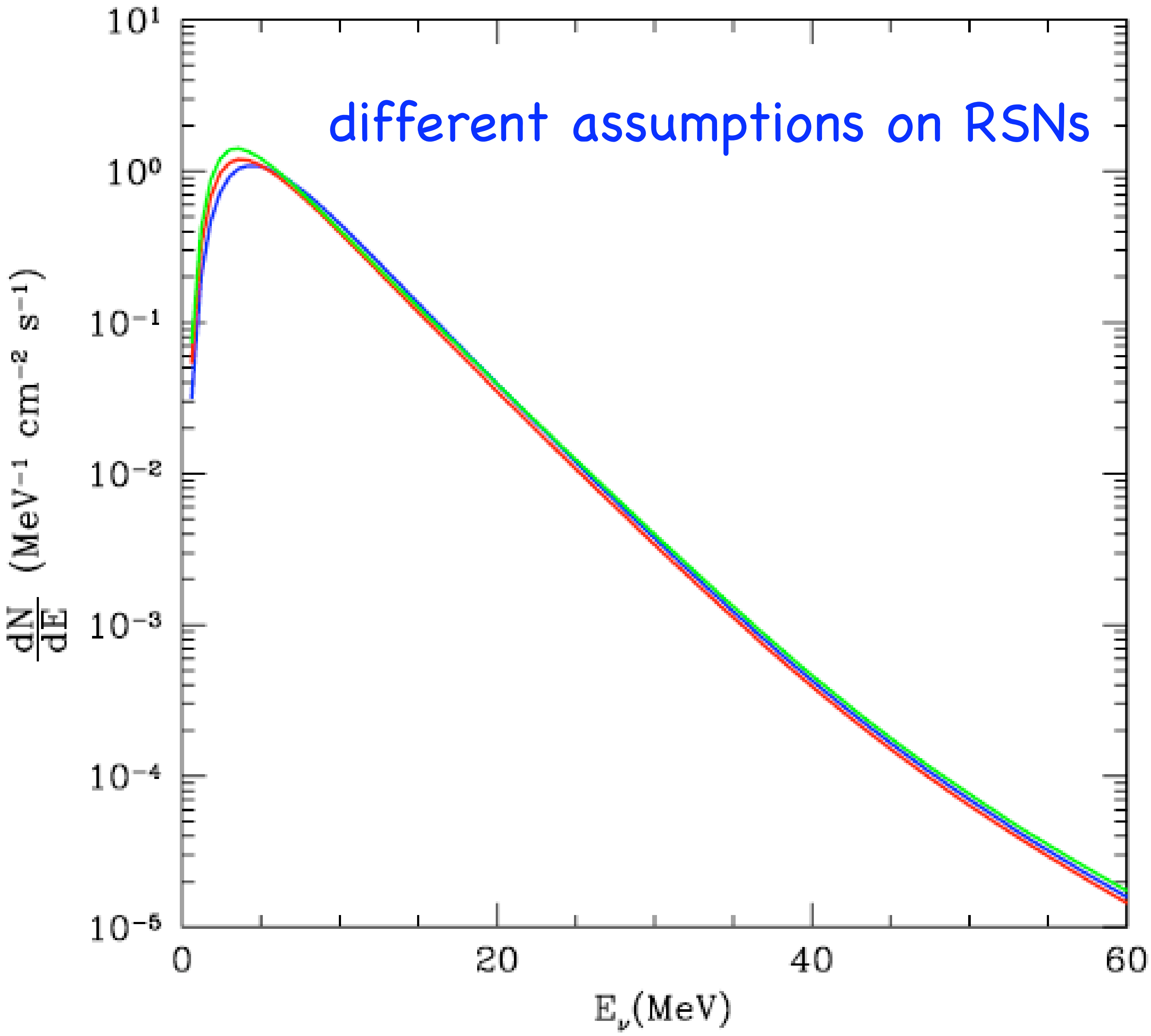
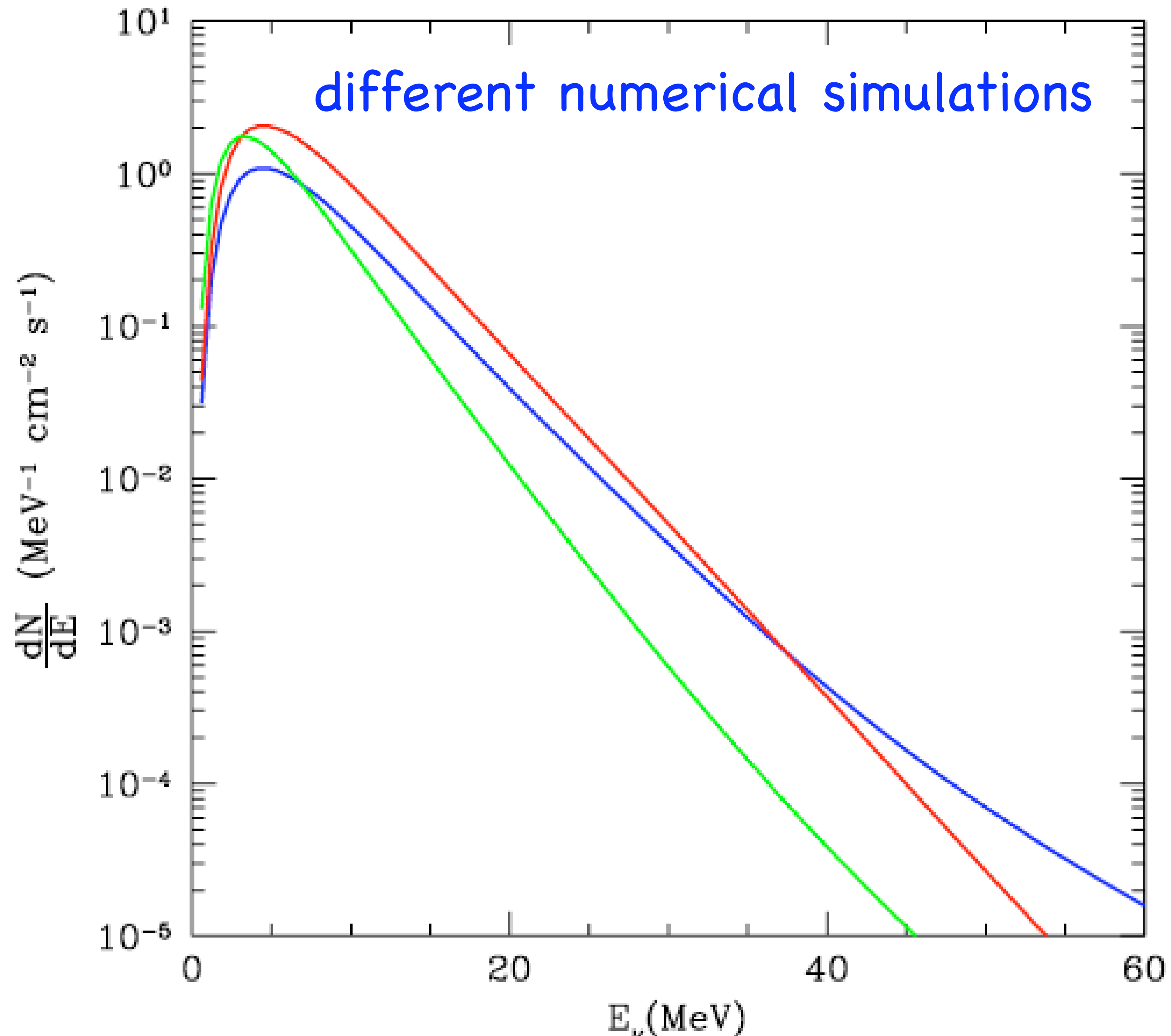
Different theoretical predictions due to different assumptions on RSNs, different numerical simulations of the neutrino spectrum and others.





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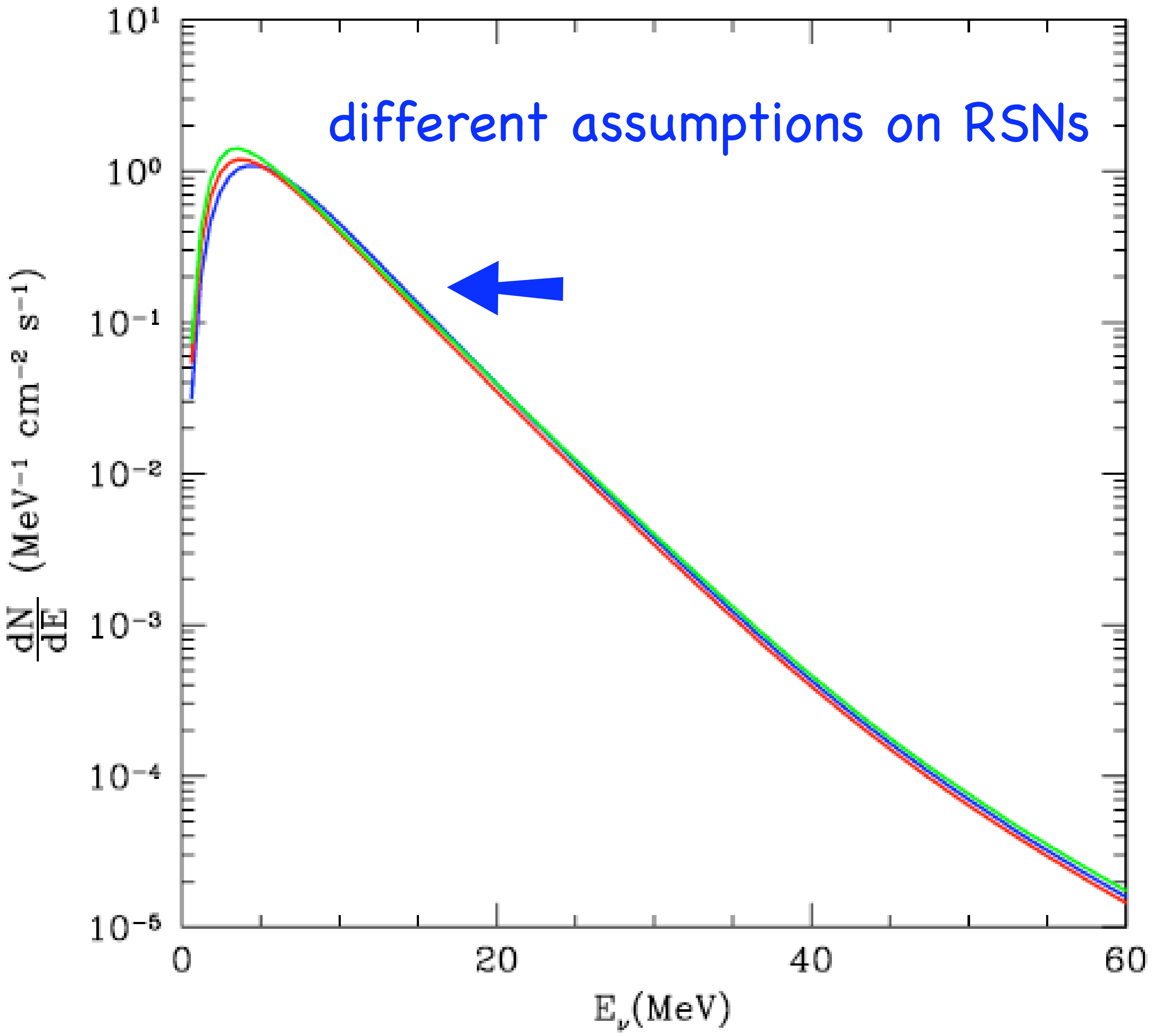

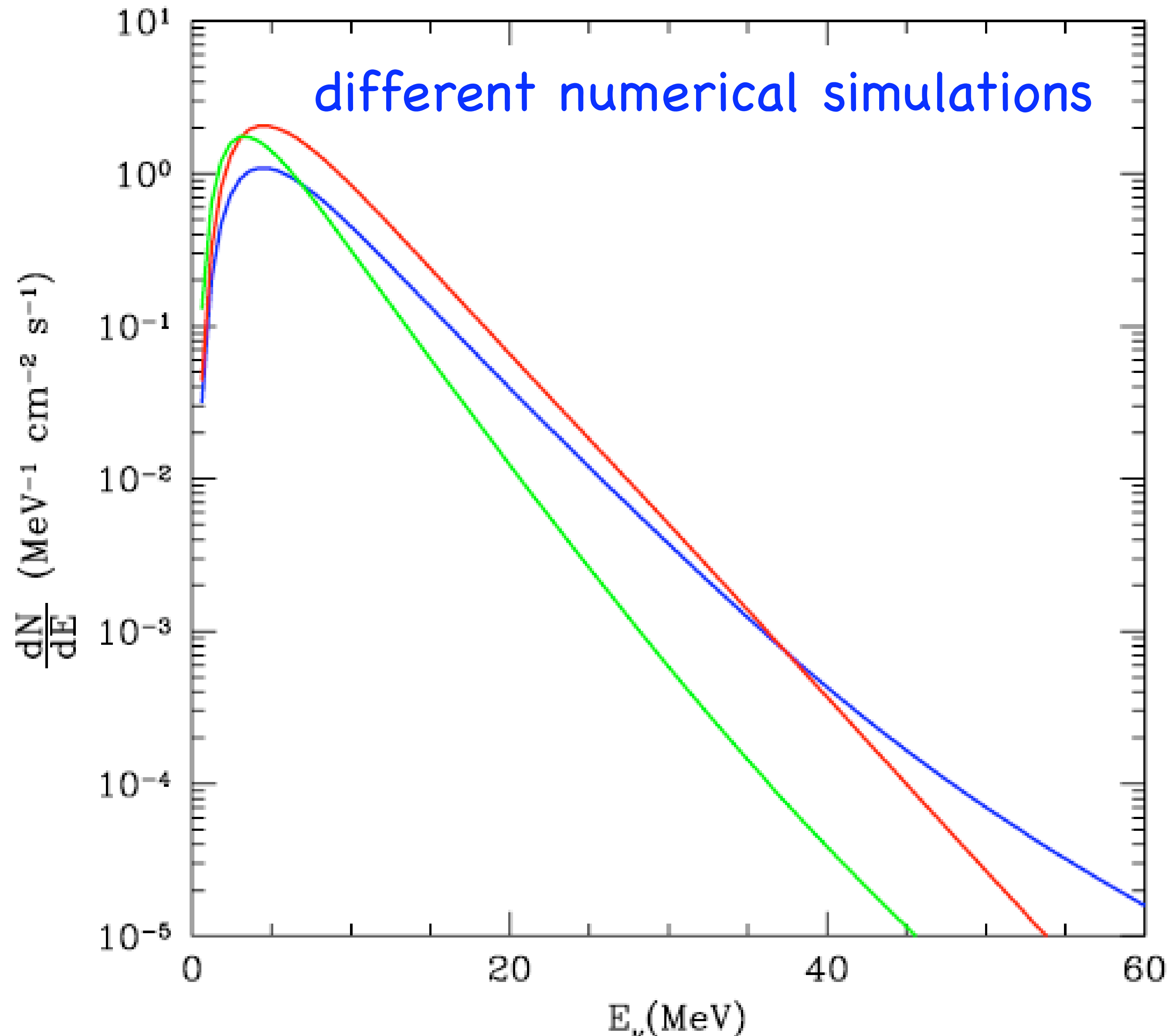

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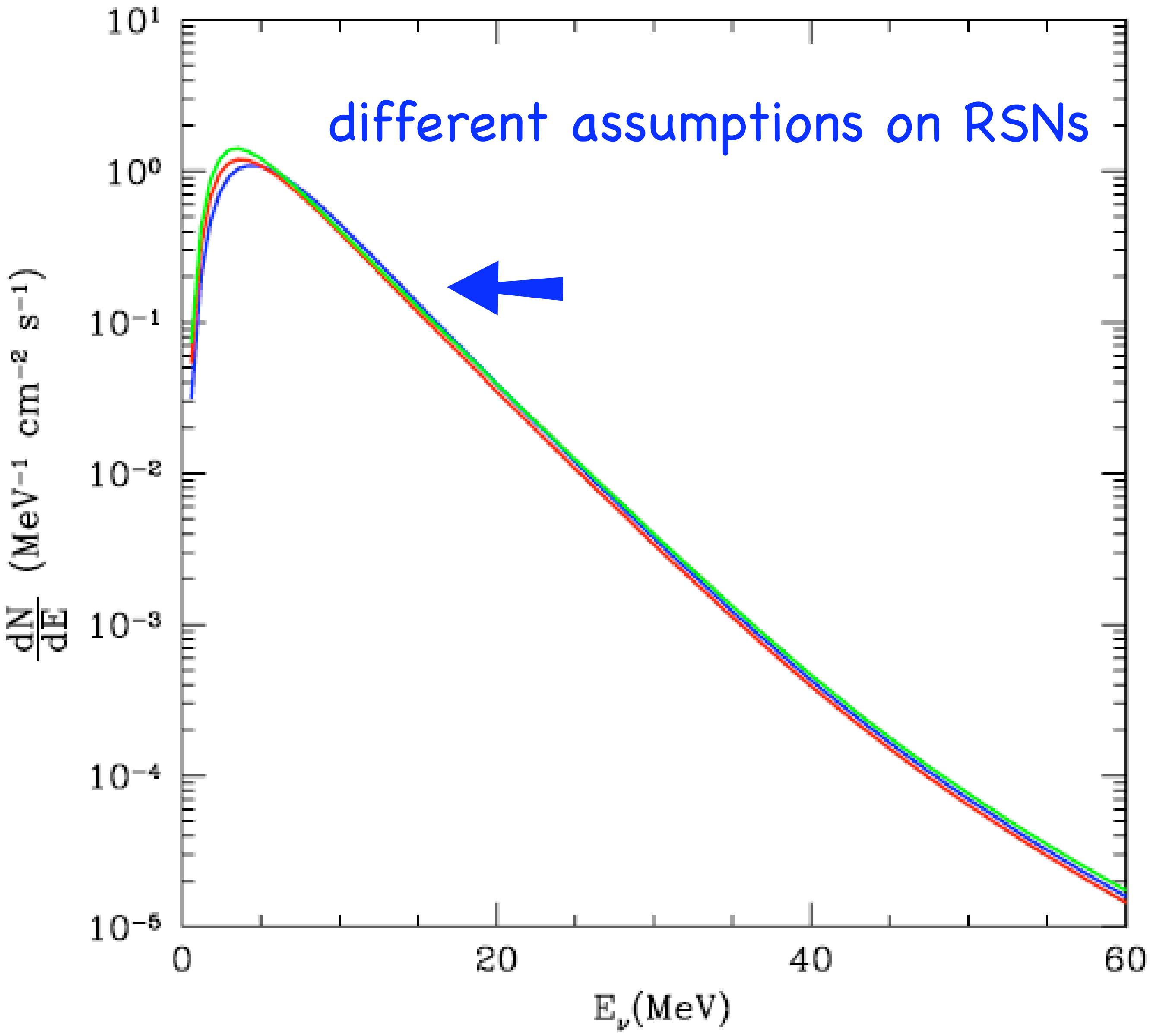
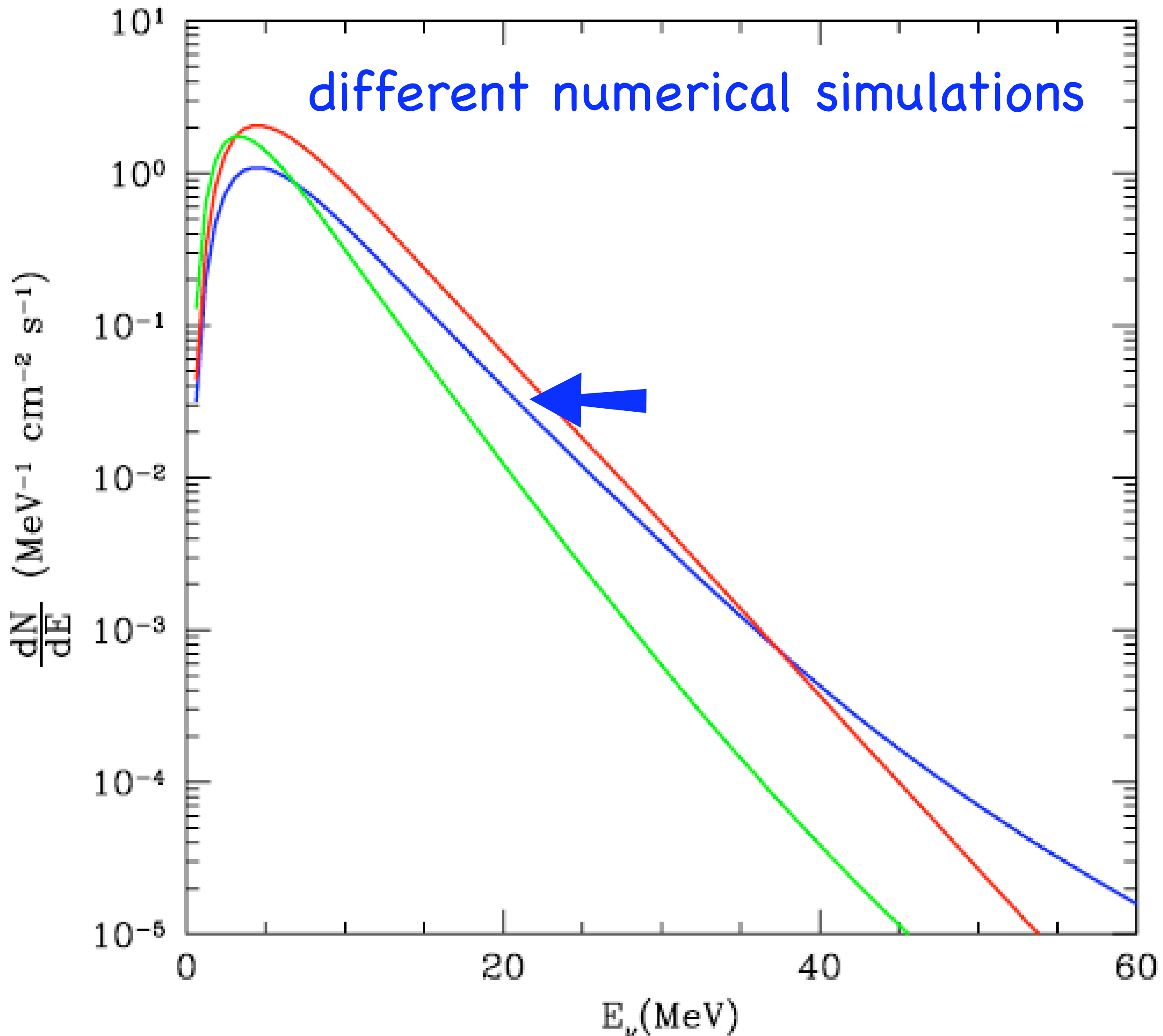




(I) The diffuse SN relic neutrino background

We will follow Ando & Sato derivation.
WE NEGLECT FLAVOR OSCILLATION EFFECTS INSIDE THE STAR because the extra dimensional neutrino-antineutrino interaction is FLAVOR BLIND!

The differential number density is a convolution of the SN rate and the spectrum, integrated over cosmic time:

$$\frac{dn_{\bar{\nu}(\nu)}}{dE_\nu} = \int_0^{z_{\mathrm{sn,max}}} dz \frac{dt}{dz}(1+z) R_{sn}(z) \frac{dN_{\bar{\nu}(\nu)}}{dE'_\nu}$$

SN rate is a fraction of the SFR:

$$R_{sn}(z) = 0.0122 \times 0.32 h_{70} \frac{\exp(3.4z)}{\exp(3.8z)+45} \times \left[\frac{\Omega_m(1+z)^3 + \Omega_\Lambda}{(1+z)^3}\right]^{1/2} \mathrm{yr}^{-1}\ \mathrm{Mpc}^{-3}$$

Porciani & Madau

The thermal relic SN neutrino spectra is:

$$\frac{dN^0_\nu}{dE_\nu} = \frac{(1+\beta_\nu)^{1+\beta_\nu} L_\nu}{\Gamma(1+\beta_\nu)\bar{E}^2_\nu} \left(\frac{E_\nu}{\bar{E}_\nu}\right)^{\beta_\nu} e^{-(1+\beta_\nu)E_\nu/\bar{E}_\nu}$$

Keil, Raffelt & Janka

(III) The UHE neutrino survival probability

$$P(E_{\nu,\mathrm{uhe}}; z_{\mathrm{uhe}}) = \exp\left[-c\int_0^{z_{\mathrm{uhe}}} dz' \frac{dt}{dz'} \mathcal{L}(E_{\nu,\mathrm{uhe}}, z')\right]$$
$$= \exp\left[-\mathcal{K}\frac{c}{H_0^2}\int_0^{z_{\mathrm{uhe}}} \frac{dz'}{(1+z')\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}} \right.$$
$$\times \int_{z'}^{z_{\mathrm{sn,max}}} \frac{dz}{(1+z)^{3/2}} \frac{\exp(3.4z)}{\exp(3.8z)+45}$$
$$\left. \times \int_0^{E'_{\nu,\mathrm{sn,max}}} dE_{\nu,\mathrm{sn}} \frac{dN_{\bar{\nu},\mathrm{sn}}}{dE_{\nu,\mathrm{sn}}} \sigma_{\nu\bar{\nu}}(s)\right]$$

Looks really ugly and complicated but is just the exponential of the annihilation cross section times the relic SN neutrino number density!

Mean free path for 10^{19} eV GZK neutrino in our local universe (z=0): 37 Mpc

(II) The UHE neutrino flux propagation

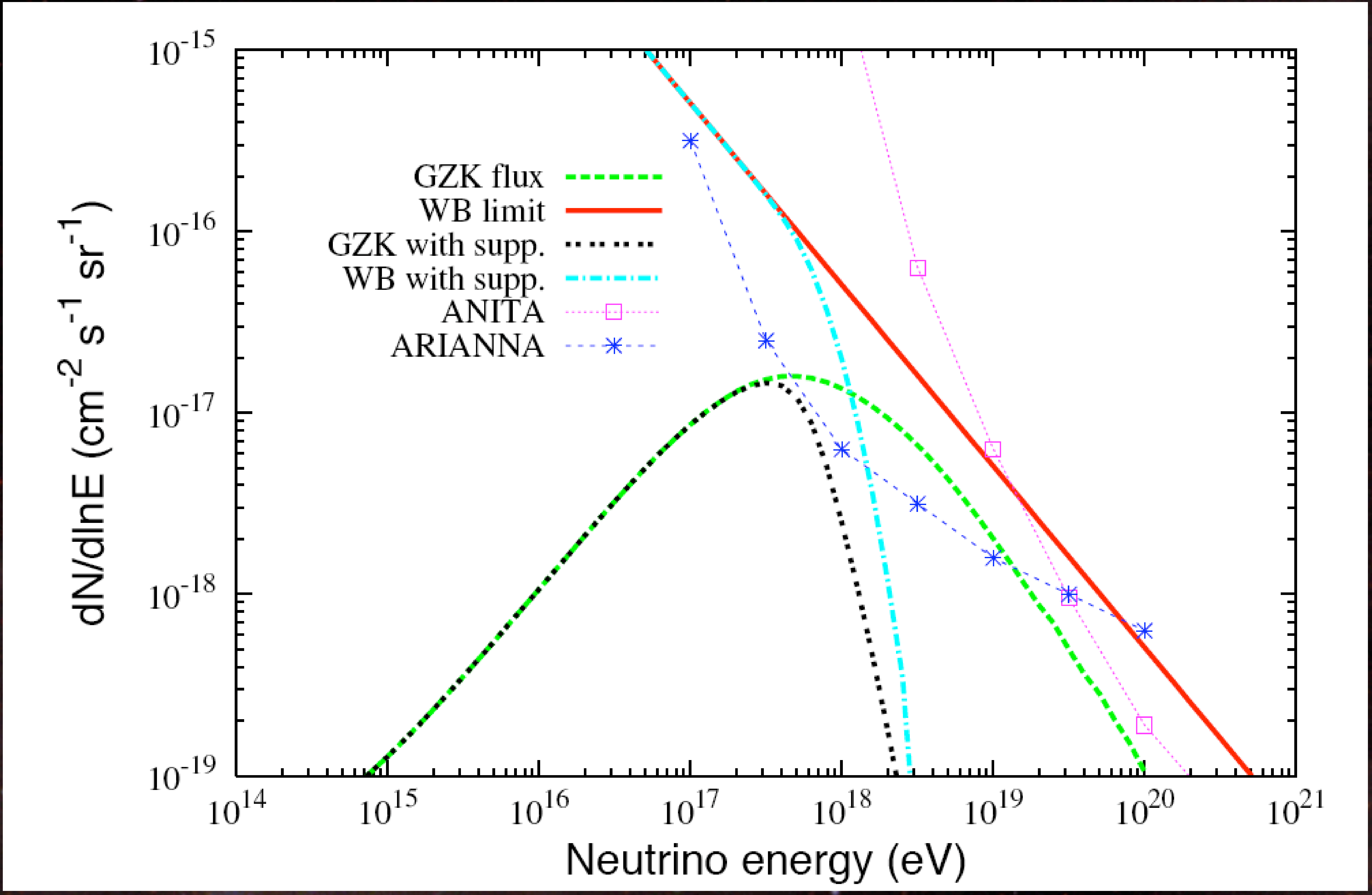
$$E_\nu J_{\nu,\mathrm{GZK}} = \mathcal{N}_{\mathrm{CR}} \int_0^{z_{\max}} dz_{\mathrm{uhe}} \frac{S(z_{\mathrm{uhe}})P(E_\nu; z_{\mathrm{uhe}})}{\sqrt{\Omega_m(1+z_{\mathrm{uhe}})^3 + \Omega_\Lambda}}$$
$$\times \int dE_p^s \frac{dN_p}{dE_p^s} Y(E_p^s, E_\nu, z_{\mathrm{uhe}})$$

N is a normalization factor which accounts for the observed UHECR fluxes.
zmax = 5 (Epoch where gravitational collapse is supposed to start)
S represents the CR source evolution.

Y is the neutrino yield function, the number of secondary neutrinos generated per unit energy interval by a CR proton, due to their interactions with CMB photons. (SOPHIA Monte Carlo code, Engel, Seckel & Stanev PRD'01, Mucke et al'99.)

The proton injection spectra (dN/dE) has an exponential cutoff at 3 x 10^{21} eV and we have integrated in the 10^{19} – 10^{22} eV energy range.

n=4 extra dimensions



ANTARCTICA & STRINGS IN ~~V~~ACQUA...

Seeing very high energy neutrinos: ESSENTIAL

Counting very high energy neutrino events: first step

More is needed (more work, of course!):

Energy distribution (MATTER EFFECTS?)

Flavor composition

Improved detection techniques

Find right observable(s) to disentangle particle physics from astrophysical effects

Keep awake for SURPRISES:

Cutoff in the spectrum due to Extra Dimensional interactions?